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DEPREDADORES PLANCTONICOS Y LA PESCA

Angeles Alvariño

Resumen

Las variaciones que se presentan en la abundancia de las diversas fases del ciclo vital de los peces constituyen factores de importancia en las investigaciones pesqueras. Dichas fluctuaciones no dependen en la mayoría de los casos del tamaño de la población adulta reproductora, ni de la magnitud de la puesta. La fase más crítica en la vida de los peces coincide con las primeras etapas de su ciclo vital, huevos, larvas y juveniles. Durante este período de la vida del pez intervienen varios agentes que diezman las poblaciones, y así sólo una cierta porción de la población original procedente de la puesta, llega a integrarse a los cardúmenes de adultos.

Se discuten los procesos bióticos y abióticos que afectan al ictioplancton y su repercusión en la magnitud del reclutamiento. Depredación es uno de los factores más importantes determinantes de las nuevas generaciones de reclutas que se integran a la población pesquera.

Quetognatos, Sifonóforos, Condróforos, Medusas y Ctenóforos, y otros zooplanctontes se alimentan de huevos y larvas de peces y de otros animales de interés comercial. Los estudios e investigaciones basados en aquellos animales tienen un doble valor, ya que todas las especies pertenecientes a esos grupos zoológicos son carnívoros y además pueden utilizarse como indicadores planctónicos, que proporcionan información detallada sobre los cambios que se producen en el océano, y que así mismo afectan a las pesquerías.

Se presentan tablas con observaciones sobre el alimento de varias especies correspondientes a los grupos planctónicos mencionados. Se discuten los datos informativos sobre la distribución y abundancia de especies depredado-

ras en el plancton de la región de California, su capacidad alimenticia y correlaciones con el ictioplancton de dicha región.

Introducción

La información sobre depredación que presento ha sido recopilada para demostrar la importancia que tiene el estudio de los organismos depredadores que integran el reino del plancton, su identificación, distribución y abundancia en relación con la distribución y abundancia de las larvas de diversas especies de peces.

Los peces marinos están dotados de una elevada fecundidad, pero los huevos y larvas resultantes de la puesta están expuestos a una mortalidad en masa, con lo cual las poblaciones logran mantener teoricamente, un cierto equilibrio demográfico en el océano.

El índice de mortalidad es muy elevado en los primeros meses de la vida del pez (Gulland, 1965; Lasker, 1965, 1975; May, 1974) llegando frecuentemente a mucho más que el 99%, y por lo tanto el estudio y determinación de los factores que influyen en la mortalidad de las larvas son de suma importancia para resolver los problemas básicos de la dinámica de las poblaciones pesqueras.

La determinación de la abundancia de los huevos y larvas de peces se iniciaron después de que Hensen (1887) diseñó un método para determinar la población adulta, basandose en el número de huevos colectados en el mar, juntamente con el grado de fecundidad de las hembras. Según Hensen, el número de huevos variaría en proporción al número de individuos en la población adulta reproductora. Ahistrom (1966) basaba estas determinaciones en el número de larvas también colectadas. Pero en ambos casos se observó que la supervivencia de huevos, larvas y jóvenes era diferente en los distintos años, de tal modo que una población muy numerosa podía dar lugar a una escasez de reclutas y viceversa.

Varios agentes físicos, químicos y biológicos (acción mecánica del viento, luz, corrientes, temperatura, salinidad, oxígeno, otras sustancias químicas y contaminantes enfermedades, alimento, depredadores y parásitos) intervienen en los procesos que se producen en el mar dando lugar a la destrucción de huevos y larvas de peces. El embate de las olas destruye un buen número de huevos y larvas de peces (Rollefsen, 1930, 1932; Devold, 1935; Zeitsev, 1968; Hempel y Weikert, 1972). La luz no es beneficiosa en cierto grado, ya que los rayos ultravioleta afectan de algún modo a los huevos y larvas de los peces (Marinaro y Bernard, 1966; Hempel y Weikert, 1972; Pommeranz, 1974). Las corrientes pueden desplazar las larvas a zonas de condiciones no propicias para su desarrollo. Los cambios de temperatura aceleran o retardan los procesos metabólicos que pueden llegar hasta niveles peligrosos para la vida del pez. La salinidad afecta a los procesos osmóticos, y la falta de oxígeno y presencia de contaminantes son factores letales para la vida de las larvas.

La pérdida de larvas por escasez de alimento es relativamente elevada, ya que los requisitos nutritivos varían en calidad y cantidad desde la fase en que se reabsorbe el saco vitelino. Hay muchos trabajos que tratan de la alimentación de las larvas de peces, y se ha llegado a la conclusión que nunca o sólo en muy raras circunstancias, el alimento puede escasear de tal modo que puede ocasionar la mortalidad en masa de las larvas de peces (Murphy, 1961). Sin embargo, la mortalidad producida por depradación no ha sido todavía determinada, ni analizada, aun cuando los biólogos más notables consideran que los organismos depredadores realizan un elevado consumo de larvas de peces, que está en relación con la abundancia y características de las especies de régimen carnívoro que aparecen en el plancton.

Los trabajos que se ocupan de los factores bióticos y abióticos que afectan a la vida de las larvas y huevos de peces, analizan uno u otros de esos factores independientemente, en relación con la abundancia de la nueva generación. El estudio detenido de estas investigaciones revela que ninguno de los factores, individualmente considerados, controla la población larval, sino que la respuesta definitiva al problema de la mortalidad de las larvas reside en el análisis de la intrincada interacción de todos los factores que influyen en el futuro de la nueva generación piscícola. De todos los factores, falta de alimento y depredación, son indiscutiblemente los que influyen en más alto grado en la supervivencia de la nueva generación. La falta de alimento no puede determinarse, ni se observa palpablemente en los estudios in situ. Sin embargo, depredación es un proceso real que se observa millones de veces, ya que está simplemente a la vista de los planctólogos que analizan sus colecciones de plancton. No obstante, el factor falta de alimento ha sido estudiado, discutido y aceptado, mientras que depredación, un hecho real que observamos continuamente en el plancton (larvas de peces en varias fases de digestión dentro del tubo digestivo de los Quetognatos, gastrozoides de los Sifonoforos, estómago de Medusas, etc.) ha sido olvidado y descartado por los biólogos pesqueros.

Los datos que se obtengan con el estudio de los procesos de depredación en larvas de peces, sus características y magnitud, serán de gran valor para la investigación pesquera, y así comprender mejor y obtener información con suficiente aproximación, del reclutamiento anual en las pesquerías de importancia comercial.

Mi experiencia personal en el estudio del plancton y el análisis crítico de la literatura relacionada con la mortalidad de las larvas de peces, demuestra sin lugar a refutación, que la depredación que ejercen los organismos carnívoros del plancton en las larvas de peces es probablemente el agente más importante en la mortalidad de las mismas. Por lo tanto, he tratado de enfocar mi investigación sobre este derrotero, y al fin he conseguido que fuese aceptado un proyecto de estudios de depredación en el reino del plancton, para que los resultados obtenidos se apliquen directamente a los estudios pesqueros.

Quetognatos, Sifonóforos, Condróforos, Medusas, Ctenóforos y otros zooplanctontes carnívoros consumen grandes cantidades de las delicadas larvas de peces, al mismo tiempo que compiten con ellas y los peces planctófagos en la captura del alimento. Varios autores también consideran definitivamente que la depredación es el factor que causa una mayor mortalidad de larvas de peces (Lebour, 1922, 1923, 1925; Bigelow, 1926; Murphy, 1961, Hempel, 1965; Fraser, 1969; Deknik et al, 1970, y muchos otros autores).

En la región de California el accidente oceanográfico más importante es la Corriente de California, cuya acción hace variar la temperatura de las aguas y el complejo faunístico de esa región, tanto en la calidad como en la cantidad de especies. Esta región oceánica presentó de 1944 a 1956 temperaturas más bajas que las normales, de 1957 hasta 1960 las temperaturas aparecían más elevadas, desde 1960 hasta 1964 las temperaturas fueron bajas en general, aunque no tanto como en la primera parte de la década de los cincuenta, y de 1965 hasta la fecha las temperaturas pueden considerarse elevadas o normales, pero no tan altas como en la segunda década de los 1950. Murphy (1961) indica que los años cálidos tienden a coincidir con una generación próspera de sardinas, y los años fríos con una generación pobre. Durante los años de temperaturas bajas, los organismos depredadores estaban constituidos por especies grandes, de elevada capacidad depredadora, y sus poblaciones eran muy abundantes, mientras que en los años con temperaturas altas, las especies eran de menor tamaño y sus poblaciones no eran muy abundantes. También hay que indicar aquí, que las temperaturas bajas contribuye a la prolongación de la fase larval y por lo tanto el período crítico de la vida de la larva se alarga, estando así expuesta durante más tiempo a las injurias ambientales y bióticas. De modo que en el caso descrito para la región de California, durante los años fríos, la depredación sería más activa, de mayor magnitud, y más intensa debido respectivamente a las características del plancton y a la extensión del período larval.

Los estudios de Stevenson (1962) sobre la distribución y supervivencia de las larvas de arenque (**Clupea pallasi** Valenciennes) en aguas de la Columbia Británica, Canadá, indica que los Ctenóforos, Medusas y Quetognatos, devoraban grandes cantidades de larvas.

Harding y Talbot (1973) en sus estudios sobre **Pleuronectes platessa** L. (platija) de la zona meridional del Mar del Norte, señalan que aunque la mortalidad causada por los organismos depredadores no ha sido determinada, se considera que es elevada y proporcional a la abundancia que presentaban los mencionados zoplanctontes carnívoros.

Alí Khan y Hempel (1974) estudiaron la abundancia de larvas de peces en el Golfo de Adén en relación con el volumen de zoplancton y encontraron que ambos parámetros variaban en razón inversa. Tengo que indicar aquí que un volumen de plancton es simplemente una magnitud sin ningún valor biológico, ya que no indica los organismos que integran ese volumen de plancton.

En resumen, un volumen de plancton es un número sin significado alguno, y hay que dejar de utilizarlo. En el plancton están representados, al menos en alguna fase de su vida, todos los grupos de invertebrados oceánicos, y los vertebrados están representados por los peces en sus formas larvales y huevos. Hay por lo tanto que conocer para cada muestra de plancton, la cantidad correspondiente a cada una de las especies que la integran.

Las investigaciones de Russell (1925) se ocuparon de la distribución de las larvas de peces en relación con otros organismos del plancton en la zona de las Islas Británicas, y Russell (1933) discute la distribución de los Quetognatos, Sifonóforos, Ctenóforos y Medusas en las colecciones obtenidas en 1930, y en 1935a, se ocupa de la abundancia de las larvas de peces en las mismas colecciones. En estos datos (Russell, 1933, 1935a) se observa, que grandes concentraciones de larvas de peces coincidían con una abundancia de planctontes herbívoros, principalmente Copépodos que servían de alimento a las larvas de los peces, y poblaciones escasas de larvas de peces se presentaban juntamente con una abundancia de Medusas, Sifonóforos y Ctenóforos.

Lucas y Henderson (1937) observaron que cuando abundaban las medusas en la región de Escocia, no se obtenían buenas capturas de arenque. Bigelow (1926) explica que las fluctuaciones en la producción pesquera del Golfo del Maine y zonas adyacentes dependía de la abundancia de los organismos depredadores en el plancton, Quetógnatos, Medusas, Ctenóforos y Antípodos, y así dice Bigelow, "IF PLANKTON STUDIES NEED ANY DEFENSE FOR THE STANDPOINT OF FISHERIES WE NEED LOOK NO FURTHER".

Hardy (1956) considera muy sugestivo el estudio de las variaciones que se presentan en el plancton y añade "NO-ONE CAN DOUBT THAT HERE LIE IMPORTANT KEYS TO A BETTER UNDERSTANDING OF SUCCESS OR FAILURE OF FISHERIES". De forma similar se manifiestan Glover, Cooper, Forsyth (1961). Hardy (1956) continúa explicando que la información sobre variaciones en el plancton proporciona "ALL-IMPORANT BACKGROUND TO THE FISHERIES, AND AT THE SAME TIME INDICATES THE MAJOR CHANGES IN THE MOVEMENT AND CONDITIONS OF THE SEA".

Hay por lo tanto, que analizar y estudiar con detalle las múltiples facetas de la investigación relacionada con las poblaciones pesqueras, esto es, el estudio de los factores bióticos y abióticos arriba mencionados, en relación con las poblaciones de larvas y juveniles, los peces en la fase de reclutamiento en las pesquerías y la población adulta correspondiente. Entonces se conseguirá conocer y tratar de determinar los efectos que tales cambios ambientales producen en la pesquería, y se podrá predecir con gran aproximación la magnitud de la población pesquera.

A continuación inserto algunos datos sobre la abundancia y alimentación de los organismos depredadores, Quetógnatos, Calentéreos (Medusas, Condróforos, Sifonóforos), Ctenóforos y otros carnívoros que integran el reino del plancton.

Quetognatos

Russell (1939) estudió las especies indicadoras en el plancton de la región de las Islas Británicas, en particular los Quetógnatos, en relación con la pesca, y así considero que varias especies del zooplancton servían en determinadas regiones, para identificar las características de las aguas, proporcionando información valiosa que se podía aplicar a los estudios pesqueros. De esta forma las especies indicadoras nos informan sobre los diversos factores bióticos y abióticos que pueden afectar al potencial de supervivencia de los pececillos recién nacidos, así como las variaciones que pueden presentarse en las rutas migratorias seguidas por las poblaciones pesqueras, ya sea locales o de gran alcance en el ámbito oceánico.

Un sencillo ejemplo de esto lo constituyen los estudios de Russell sobre la influencia de las aguas identificadas por **Sagitta setosa** y **S. elegans** en la región de las Islas Británicas, en relación con la riqueza pesquera y las condiciones oceanográficas.

La copiosa información que hay publicada sobre el tema de los indicadores planctónicos muestra con toda evidencia que las múltiples correlaciones que existen entre las condiciones de las pesquerías y las características del ambiente oceánico no pueden explicarse sin tener un conocimiento detallado y básico del plancton. Depredación es otro aspecto interesante relacionado con los Quetognatos, ya que estos animales se alimentan activamente de larvas de peces y de otros animales de importancia comercial, devorando además otros zooplanctontes que sirven de alimento tanto a aquellos organismos como a los peces adultos.

En la literatura publicada aparecen muchos datos sobre la alimentación de los Quetognatos, señalando que estos animales consumen peces y otros zooplanctontes, Copépodos, otros Crustáceos, Medusas, Sifonóforos, Salpas, otros Quetognatos, etc., (Oye 1918, Graham et al 1954; Suárez-Caabro, 1955, Hardy, 1956; Alvariño, 1962, 1965, 1974; Della Croce, 1963; Johnson y Snook, 1963; Nair y Rao, 1973; Jumao-as y Westernhagen, 1975) y otros).

Stone (1969) determinó el alimento en el tubo digestivo de los Quetognatos procedentes de la región de la Corriente de las Agujas, y no aparecían larvas de peces, lo cual es extraño ya que en esa región hay poblaciones abundantes de Clupeidos y Merluccidos.

Thomson (1947) al estudiar la población de Quetognatos del SE de Australia indica que se alimentan de larvas de peces, devorando además Copépodos y otros Quetognatos, y así discute el papel que desempeñan en el ciclo alimenticio de las comunidades pelágicas, en donde actúan como depredadores, competidores en la captura de la presa, y a su vez víctimas, de modo que los Quetognatos asumen estas tres categorías en relación con los peces pelágicos.

Bigelow (1926) considero que los Quetognatos consumían más Copépodos que los peces, y Lebour (1923) indicaba que en una comunidad pelágica los Copépodos comprenden un 60% al 80% del plancton, y son devorados ávidamente por los planctontes carnívoros entre los que se encuentran los Quetógnatos. Wickstead (1959) considera que los Quetógnatos son el componente carnívoro más importante del plancton, basándose en el gran número de ejemplares que aparecen en las colecciones con el tubo digestivo lleno de larvas de arenque, y así se explica que deben afectar seriamente a esta pesquería.

Al analizar las colecciones de plancton se observa que los Copépodos aparecen con mayor frecuencia llenando el tubo digestivo de los Quetognatos, lo cual puede ocurrir por varias causas. Así los Quetognatos necesitan, por ejemplo, capturar más Copepodos que larvas de peces, para saciar sus requisitos nutritivos, ya que el exoesqueleto de los Copépodos no es digestible y además permanece más tiempo en el intestino de los Quetognatos antes de ser expulsado al exterior. Además, los Copépodos son generalmente los organismos más abundantes en el plancton y así siempre están a disposición de los depredadores. Lee (1974) explica que como las proteínas no se pueden almacenar y los lípidos neutrales aparecen a niveles bajos en el plancton, los Quetognatos y Ctenóforos, así como también los Sifonóforos, Medusas y Condróforos no pueden almacenar reservas alimenticias y parecen de inanición en unas 48 horas aproximadamente, al menos en lo que respecta a las especies de los dos primeros grupos mencionados. La gran apetencia por proteínas que tienen estos organismos trae como resultado que ostentan una gran actividad depredadora elevada al máximo grado. Así que es obvio que dichos organismos obtendrán la mayor eficiencia alimenticia devorando larvas de peces, de contenido proteínico más alto y con un mínimo de residuo no digerible.

He observado que en el intestino de los Quetognatos aparecen con más frecuencia larvas de peces en una fase de desarrollo avanzada que larvas en la fase del saco vitelino. Esto puede ser debido a que las larvas en la fase de saco vitelino son digeribles con mayor rapidez, o que los Quetognatos detectan con mayor eficacia las vibraciones producidas al nadar por las larvas más desarrolladas que las recién nacidas. Es posible que ambos factores sean válidos, es decir, digestión rápida y mayor eficacia en la captura de larvas más desarrolladas, aunque éstas tengan un potencial natatorio mayor.

Mironov (1960) ha tratado de determinar la ración diaria que precisan los Quetognatos y considera que cuanto más largo es el período de digestión mayor es el número de individuos que aparecen con el intestino lleno de alimento, y recíprocamente, cuando la digestión ocupa un corto período, aparecen más individuos con el tubo digestivo vacío. Sin embargo, además de los factores que intervienen en el proceso alimenticio, captura del alimento, digestión, excreción, abundancia de alimento; el tiempo que dura la digestión varía en función de la temperatura. En mis estudios he observado un porcentaje mucho más reducido de ejemplares con el estómago vacío en las colecciones procedentes de zonas cálidas que de regiones frías, lo cual puede considerarse como una evidencia de la rapidez de la digestión.

Varios investigadores han estudiado la alimentación de los Quetognatos en el laboratorio, Lebour (1922, 1923), Parry (1944), Mironov (1960), Reeve (1964), Kotori (1969), Reeve et al (1970), Newburry (1972), Reeve y Walter 1972), Nagasawa y Marumo (1972), Takana (1971), Alvariño (datos inéditos). En la región de California he encontrado hasta más del 60% de los Quetognatos con el intestino lleno de larvas de peces en proceso de digestión.

Al analizar los datos que presentan varios biólogos, se observa una estrecha relación inversa entre la abundancia de Quetognatos y larvas de peces. Así Corbin (1947) estudios sobre la abundancia en la región de las Islas Británicas de larvas de **Scomber scombrus** (caballa) y **Sardina pilchardus** (sardina) en relación con las especies de Quetognatos, **Sagitta setosa, S. tasmanica S. lyra** y el Sifonóforo **Muggiaea atlantica,** indican que la presencia de las larvas de estos peces coincidían con escasez de Quetognatos y Sifonóforos, y elevadas concentraciones de éstos con pocas larvas de aquellos peces.

Furnestin (1960) presenta la distribución cuantitativa de los Quetognatos **S. setosa, S. enflata, S. serratodentata, S. bipunctata** en relación con la distribución de larvas de **Engraulis encrasicholus** (anchoa) y señala que elevadas concentraciones de aquellas coincidía con escasez de larvas de anchoa y viceversa. Similarmente se observa en los trabajos de Bal y Pradham (1952) para la región de Bombay, Williamson (1961) para las pesquerías escocesas, Southward (1962) para la región de Eddystone, Rao (1962) para la bahía Corniga en India, Tsurata (1963) para el Mar de Bering, las islas Marshall, Phoenix Gilbert y el Atoll Bikini; Lakkis (1971) para la región Libanesa del Mediterráneo, Bainbridge y Forsythe (1972) para el noroeste del Mar del Norte, Ali Khan y Hempel (1974) para el Golfo de Aden, Boltovskoy y Mostajo (1974) en Argentina, Sameoto (1975) para la Bahía de Santa Margarita en Nueva Escocia (Canadá). Mís datos inéditos sobre la abundancia en tiempo y espacio de varias especies de Quetognatos y larvas de peces en la región de California (estudio de muestras mensuales sobre toda la región y durante varios años) indican que una abundancia elevada en las poblaciones de Quetognatos coincide con escasez de larvas de peces y viceversa.

Hay que considerar aquí los cálculos de Sameoto (1972) al estudiar la población de **Sagitta elegans** en la Bahía de Santa Margarita de Nueva Escocia, en donde los Copépodos constituyen el alimento principal. Sin embargo la máxmima concentración de biomasa de **S. elegans** ocurre en aquella región en el invierno y comienzos de la primavera, precisamente cuando la producción de Copépodos alcanza el mínimo. Sameoto (1972) calculó la energía respiratoria de esa población de **S. elegans** durante dicho período, y así mismo los Kilo-calorías consumidas, observando que la producción de Copépodos es insuficiente para mantener el metabolismo de la población de **S. elegans,** y por lo tanto este Quetognato debe de alimentarse además de otros organismos del plancton que no se encontraron en el contenido estomacal de los ejemplares de **S. elegans** analizados. Podría tratarse de larvas de peces, que suministrarían un buen aporte de energía, y que por ser digeridas rápidamente no queda mucha oportunidad de que sean observadas en el contenido estomacal de los Quetognatos.

Quiero hacer resaltar aquí, que los cálculos realizados por algunos biólogos pesqueros en cuanto al efecto que podría causar esta depredación en las poblaciones de peces, no están basados en situaciones reales, ya que no coordinan la presencia de Quetognatos con larvas de peces en tiempo y espacio, ni tampoco consideran la capacidad depredadora de varias especies, su abundancia y distribución. En esos cálculos se olvidan que existen además otros depredadores, así como las condiciones físico-químicas del ambiente oceánico que influyen en el índice de la depredación, en la comunidad pelágica.

Calentereos

Bigelow (1926) consideraba que los Calentereos incluyen los animales más voraces del plancton oceánico. Duvault (1965) indica que se alimentan exclusivamente de animales vivos, pequeños invertebrados y larvas de peces. Todos los Calentereos son carnívoros, y se puede observar su acción depredadora en las poblaciones de peces.

Bal y Pradham (1952) estudiaron el zooplancton de la región de Bombay desde 1944 hasta 1947 y observaron que una gran abundancia de Sifonóforos, Medusas y Ctenóforos coincidía con una cantidad mínima de larvas de peces en aquellas regiones y viceversa.

Los Calentereos (Condróforos, Sifonóforos y Medusas) poseen un sistema especial que produce un veneno que inyectan a sus víctimas, ocasionando en ellas un letargo, parálisis y muerte. La captura del alimento en los Calentereos y en varios Ctenóforos está relacionado intimamente con esta producción e inoculación de veneno.

El Orden Condrófora incluye animales que habitan la superficie oceánica. Se trata de organismos extremadamente voraces, alimentándose de huevos y larvas de peces y formas larvarias y adultos de otros zooplanctontes.

La información publicada sobre el alimento de los Condróforos incluye solamente los géneros **Porpita** y **Velella.**

Porpita percibe las vibraciones que producen los animales al desplazarse en el océano (Horridge, 1966; Mackie, 1959), y así tienen una gran habilidad para capturar el alimento, que incluye Copépodos grandes, que también son carnívoros, y que llegan a constituir hasta un 90% de la dieta (Bieri, 1970) junto con larvas de peces, Crustáceos y Moluscos, Medusas, Nematodes etc.

Vetella navega a vela surcando los océanos al azar de los vientos, y no puede por lo tanto dirigirse por su propio impulso en cualquier otra dirección, y así se alimenta de los organismos que habitan los estratos más superficiales del océano, a los que captura en las rutas que sigue marcadas por el viento. Huxley (1858), Lebour (1947), Totton (1954), Bieri (1970) encontraron restos de Copépodos y de larvas de peces en el estómago de estos animales. Bieri (1961) analizó el alimento de **Velella lata** en la fase postlarval, procedente de la región de San Diego, California, y encontró que los gastrozoides estaban llenos de huevos de peces, principalmente de **Trachurus symmetricus,** huevos de Eufaúsidos y larvas de otros peces, así como varios Copépodos, Eufáusidos y otros invertebrados y sus larvas e incluso también aparecían diatomeas. Los ejemplares de **Velella** que, estudié, procedentes de la Corriente de Perú, contenían grandes cantidades de huevos y larvas de **Engraulis ringens** (anchoa peruana).

La anatomía de los Sifonóforos está perfectamente diseñada para pescar activamente y desplazarse rápida y furtivamente en el agua. Los Sifonóforos son transparentes en su mayor parte, y extienden sus redes de tentáculos que llegan a alcanzar varios metros.

El Sifonóforo **Epibulia ritteriana** flota en la superficie de las aguas, sus tentáculos alcanzan muchos centímetros de longitud, y se alimentan de organismos del epiplancton, larvas de Clupeidos, Engraulidos y de otros peces (Alvariño, 1972). He observado **E. ritteriana** con los gastrozoides llenos de restos de larvas de **Sardinops, caerulea, Engraulis mordax, Cololabis saira** y órganos luminosos de **Myctophidos.**

Physalia physalis (vulgarmente llamada carabela) es una trampa mortífera para los peces, alimentándose de Trachuridae, Exocoetidae y otros) dejando a los peces inmovilizados con el veneno que les inocula y así son capturados fácilmente para ser digeridos en los gastrozoides.

Los Sifonóforos Physonectae varían de profundidad en océano rapidamente mediante la acción del pneumatóforo y las pulsaciones de los nectóforos acoplados en el nectosoma, que en rítmicas contracciones propulsan al animal velozmente al recibir una excitación. De esta forma capturan pececillos y crustáceos.

De las 150 especies de Sifonóforos reconocidos, solamente se ha observado el alimento en nueve especies, de modo que aquí hay todavía un amplio campo de estudio para los biólogos interesados en estas investigaciones.

Medusas

Las Medusas, parientes próximos de los Sifonóforos, adoptan formas variadas y caprichosas con multitud de gamas de colores. El estudio de estos animales es interesante para el conocimiento de la fauna, ecología, indicadores de condiciones oceánicas y depredación, así como en los modernos estudios farmacológicos en relación con las investigaciones médicas.

Todas las medusas son carnívoras devorando larvas de peces y de otros animales de importancia comercial (Crustáceos, Moluscos) y también Anelidos, Quetognatos, Sifonóforos, otras Medusas, Ctenóforos, Apendicularis, Dinoflagelados, etc. Al igual que los demás Calentereos y muchos Ctenóforos, las Medusas producen un veneno con el cual atacan a las víctimas, dejándolas inmóviles y dispuestas para ser devoradas con mayor facilidad. Varios autores indican la importancia que tiene el estudio de la distribución de estos animales que destruyen huevos y larvas de peces, causando así grandes daños a las pesquerías (Mayor, 1917, 1919; Joubin, 1924). Russell (1970) explica que en vista del tamaño y abundancia que alcanzan las Schyphomedusas, estos organismos han de desempeñar un papel importante en la economía del mar, como depredadores y en la competición con los peces en la captura de alimento.

Desde hace muchos años se sabe que las medusas son enemigos peligrosos de los peces a los que atrapan, envenenan y apresan con los tentáculos. Sin embargo las larvas y alevines de varias especies de peces (Gádidos, Trachuridos, Clupeidos etc.) se congregan bajo la umbrela de las grandes medusas, constituyendo así aparentemente una asociación biológica. Se ha considerado que las crías de algunos peces están protegidas bajo el hecho de las medusas de los ataques de otros animales que evitan aproximarse a la medusa. Algunos autores indican que los pececillos son posiblemente inmunes a las toximas de las medusas. Hay muchos trabajos sobre la posible asociación de larvas y peces jóvenes con las medusas. Algunos de los pececillos que acompañan a las gigantescas Scyphomedusas nadan entre los tentáculos, y aunque algunos perecen bajo la acción de los dardos envenenados descargados por el huésped y son devorados por las medusa, otros prosiguen su vida, a expensas de aquellas víctimas, protegidos de otros depredadores. Se tienen datos de que peces asociados con esas medusas presentan a veces signos de envenenamiento, lo que hace pensar que, inicialmente, los pececillos buscan el cobijo y protección de la sombrilla protectora de la medusa, atraídos además por los suaves movimientos de los tentáculos. Algunos son alcanzados por el veneno del huésped, pierden actividad, quedando a merced de la Medusa y ser devorados finalmente, mientras que muchos otros sobreviven hasta alcanzar mayor tamaño y edad en que pueden evadir a sus agresores sin la ayuda externa. Aquí, el sacrificio de unos pocos constituye una ventaja para muchos. En esta asociación, la medusa, el individuo, encuentra alimento fácil en estas porciones de cardúmenes que la acompañan, y la especie de peces correspondiente, no el individuo, logra que muchos de sus individuos logren sobrevivir el período más delicado de su vida.

Estas asociaciones no constituyen el tema del presente trabajo, pero están relacionadas en cierto modo con depredación, y por eso incluyo este comentario general.

Mayer (1910) incluye unas 737 especies de Medusas en su Tratado General de las Medusas del Mundo, y Kramp (1961) menciona unas 800 especies. Las observaciones que hay publicadas sobre el alimento de las medusas abarca unas 51 especies, y 34 de ellas se han observado alimentándose de larvas de peces y peces jóvenes. Sin embargo se podía considerar que la mayor parte de las medusas han de incluir también peces en su dieta. Lebour (1922, 1923) realizó muchos experimentos en el laboratorio estudiando la alimentación de los organismos marinos, y así ha observado que las larvas de peces y alevines constituyen el alimento preferido de las medusas.

Bigelow (1926) indica que las Medusas y en particular **Aurelia aurita** son extremadamente abundantes en el Golfo del Maine y regiones adyacentes, y que han de causar grandes estragos en las crías de peces que se reproducen en estas regiones.

Candeias (1931) observo en junio de 1926 grandes cantidades de **Liriope tetraphylla** y una ausencia total de **Sardina pulchardus** en una región del Atlántico Ibérico donde normalmente estos peces son muy abundantes.

Russell (1931), Lucas y Henderson (1937) sugieren que la abundancia de **Gadus merlangus** en el Mar del Norte estaba en razón inversa con la abundancia de la medusa **Cyanea.** Lucas y Henderson (1937) observaron que la escasez de **Clupea harengus** en el Mar del Norte coincidía con abundancia de medusas y viceversa, y que en 1931 se presentó una extremada abundancia de medusas y del calamar **Ommatostrephes sagittatus,** coincidiendo con la desaparición de las ricas pesquerías de arenque frente a las costas de Shetland.

Russell (1938) se ocupa de las capturas mensuales de medusas durante 1930 a 1937 y la cantidad total de larvas de peces, exceptuando los Clupeidos. En 1931, 1932, 1934, 1935 aparecían pocas medusas y elevadas cantidades de larvas de peces. Algo similar se observó en 1936 y 1937, aunque en un orden distinto de magnitud en cuanto a los peces, y en 1930 se encontraron grandes cantidades de medusas y pocas larvas de peces. Sin embargo, la falta de datos sobre Clupeidos dificulta esta comparación, ya que en uno u otro caso, las medusas podían devorar larvas de arenque y otros Clupeidos sin alterar el valor numérico correspondiente a las demás especies de peces.

Fraser intentó calcular en 1969, el efecto que pueden producir las Medusas en el reclutamiento de los peces marinos, y así, considerando un ejemplar de **Cyanea capillata** de unos 50 mm de diámetro, observó que capturaba 80 larvas de peces además de anfípodos, Eufáusidos, Copépodos, larvas de invertebrados, etc. en unas 6 horas y media. Otro ejemplar de **Cyanea capillata** de unos 45 cm de diámetro que pesaba 6 kg. (Fraser, 1969) requeriría 3570 gr de alimento, unos 166 × 10^4 **Calanus**, que equivalen a unas 15.000 larvas de peces. La hidromedusa **Staurophora mertensi**, muy abundante en algunas regiones en donde aparecen ejemplares de 15 mm hasta 164 mm de diámetro, y Fraser (1969) observó que un ejemplar de 15 mm de diámetro capturaba en pocas horas 8 larvas de peces juntamente con otros organismos (Copépodos, Anfípodos etc.) y todo ello lo digería en unos 45 minutos.

Fraser (1969) indica que aunque **Aurelia aurita** no consumiese peces después de alcanzar 50 mm de diámetro, y solamente 1/4 del alimento ingerido incluyese larvas de peces, cada individuo de esta especie consumiría de 400 a 500 pececillos.

Neale y Bayly (1974) encontraron una relación inversa entre la abundancia de **Aurelia aurita** y **Australomedusa baylii** y la cantidad de larvas de peces en varios estuarios de Victoria (Australia).

Russell (1970) analiza el efecto de las medusas en las pesquerías de **Homarus vulgaris** y señala que los bogavantes escaseaban justamente cuatro años después de que se habían registrado medusas en grandes cantidades.

Ctenóforos

Los Ctenóforos son también de gran importancia en la economía de las comunidades planctónicas. Lebour (1922, 1923, 1925) estudió el alimento de estos animales, observando que capturan todo lo que encuentran en el plancton, incluyendo larvas de peces, llegando a encontrar varias larvas de peces por estómago de Ctenóforo. Bigelow (1926) explica que son tan voraces que barren prácticamente del plancton la región que habitan dejándola limpia, así ningún zoplanctonte puede coexistir con ellos. Estos animales en sus movimientos peculiares en circunvoluciones rizando el rizo, exploran grandes volúmenes de agua, y así capturan enormes cantidades de organismos.

Hardy (1956) observó los bancos de pesca del arenque en Yorkshire, en donde a veces aparecen grandes acumulaciones de Ctenóforos, y comenta que en esas situaciones los Ctenóforos han de ocasionar grandes destrozos en las crías de arenque, y así las variaciones drásticas que se observan en estas pesquerías de un año para otro en aquellas regiones, deben estar íntimamente relacionadas con la abundancia de los Ctenóforos, ya que en los años que los Ctenóforos aparecen en grandes concentraciones la generación de arenque resultaba muy reducida y viceversa.

Russell (1931) discute la importancia de los Crustáceos en la economía del mar, y además indica que la abundancia de depredadores planctónicos, en especial los Ctenóforos, deben producir una destrucción en las poblaciones de Copépodos, de manera que no queda suficiente alimento para las poblaciones de peces. Russell (1930 a, b y 1935 a) indicaba que en la primera quincena de mayo de 1930 se había presentado un máximo de larvas de peces (exceptuando los Clupeidos), pero en la segunda quincena la curva descendía dramáticamente, coincidiendo con una enorme concentración de Ctenóforos acompañados por el Sifonóforo **Stephanomia bijuga** y las medusas **Bougainvillia** y **Obelia.** Russel añade que en junio, julio y agosto del mismo año la cantidad de Ctenóforos, Medusas y Sifonóforos se mantuvo elevada y durante esos meses las larvas de peces aparecían a un nivel bajo, lo cual no es normal en aquellas regiones a la entrada del Canal de la Mancha. Russell (1935a) indica que en 1929 las capturas de larvas de peces fueron inferiores a las correspondientes a los años 1930 a 1934, y explica que en 1929 los Ctenóforos **(Beroe cucumis, Bolinopsis infundibulum, Pleurobrachia pileus)** aparecían extremadamente abundantes durante el período de reproducción de los peces, y así devorarían grandes cantidades de larvas de peces y otros organismos del plancton, actuando como depredadores y competidores por alimento.

Kinkaid (1915) considera que **Pleurobrachia** es un enemigo muy peligroso de las ostras de Washington, devorando las larvas de estos moluscos.

Beroë es de mayor tamaño que los demás Ctenóforos y Bigelow (1926) lo considera aún más voraz que las demás especies del grupo, aunque es siempre mucho menos abundante, y se alimenta principalmente de otras especies de Ctenóforos **(Pleurobrachia** y **Bolinopsis)** que son siempre muy abundantes. De modo que **Beroë** tiene a su cargo, en cierto modo la limitación de las poblaciones de su grupo (Chun, 1880; Lebour, 1922; Bigelow, 1926; Kamshilov 1960 a.b), y Mantenfel (1941) considera que toda esta regulación afecta así mismo a la supervivencia del arenque del Mar de Bering.

Otros organismos del zooplancton se alimentan también de larvas de peces y de otros invertebrados, resultando así ser también competidores y depredadores. Entre estos se encuentran los Copépodos, Eufáusidos, Anfípodos, otros Cructáceos, Cefalópodos.

Russell (1931) ha revisado los estudios realizados por varios biólogos sobre el alimento de los peces, y demuestra la importancia que tienen los Copépodos pelágicos durante alguna fase de su ciclo vital. Así los Copépodos constituyen el alimento básico de los peces pelágicos, sardinas, anchoas, arenques, jureles, que comprenden làs poblaciones pesqueras más numerosas del mundo. Por lo tanto, resulta que los Copépodos son el eslabón principal entre la complicada trama alimenticia que abarca de las diatomeas hasta los animales carnívoros.

Aunque la mayor parte de los Copépodos son fitófagos, hay especies de régimen omnívoros carnívoro y (Esterly, 1916; Lebour, 1922, 1923; Wickstead, 1962).

Garstand (1900) realizó cultivos de **Blennius ocellaris** y se encontró con que las larvas de estos peces eran devoradas por Copépodos Harpacticidos, principalmente **Idya furcata,** que se introdujo accidentalmente en el sistema de los acuarios. Estos Copépodos eran de tal rapacidad que incluso atacaban a **Gobius minutus** de 25 mm de longitud, al igual que devoraban las larvas de **Blennius,** tanto las vivas como las muertas o moribundas.

Lebour (1922) explica que los Copépodos omnívoros **Temora longicornis, Centropages typicus, Calanus finmarchicus, Labidocera wollastoni** adoptan una dieta mixta que incluye diatomeas y otros copépodos, y el Copépodo tan común en todas partes, **Anomalocera patersoni** se alimenta de larvas de peces y de otros Copépodos (Lebour, 1922, 1923). Las hembras de **Candacia aethiopica** se alimentan de larvas de Myctophidos (Wickstead, 1965).

Los estudios realizados en el laboratorio por Lillelund y Lasker (1971) demuestran que varias especies de Copépodos hieren, capturan o ingieren larvas de peces. Así **Labidocera jollae, L. trispinosa, Pontellopsis occidentalis,** las especies de Copépodos más comunes en aguas de superficie de la Corriente de California, atacaban a las larvas de peces presentes en el mismo acuario. Sin embargo la eficacia de captura disminuía al aumentar el tamaño de las lravas, y si se añadían larvas de **Artemia** a los cultivos, **L. trispinosa** devoraba menos larvas de peces. Lillelund y Lasker (1971) explican que, aunque estos Copépodos capturan e ingieren larvas de anchoa en el laboratorio, en las colecciones de plancton nunca se encuentran Copépodos devorando larvas de peces, mientras que es muy frecuente observarlas en el tubo digestivo de Quetognatos, Sifonóforos, Medusas, Ctenóforos y Condróforos.

Algunos Eufáusidos del Golfo del Maine (Bigelow, 1926) principalmente **Meganyctiphanes norvegica** devoran larvas de peces, Copépodos y Diatomeas. **Euphasia pacífica** y las larvas de **Engraulis mordax** son las especies de Eufáusidos y Clupeidos respectivamente más abundantes en la región de la Corriente de California. Theilacker y Lasker (1973) mantuvieron en el laboratorio **E. pacífica** junto con larvas de anchoa, y observaron que estos Eufáusidos capturaban las larvas de anchoa recién nacidas, pero que cuando las larvas aumentaban de tamaño y con ello su movilidad y rapidez, las capturas se reducían progresivamente hasta llegar a cero, de forma similar a lo que se explica más arriba para varias especies de Copépodos.

Parathemisto libellula y **Beeudalibrotus sp.** devoran larvas de **Gadus callarias** (Lee, 1966). **Calliopis** sp. **Parathemisto pacifica, Anomyx** sp. se alimentaban de **Cliona limacina** (Fukushi, Yoshida, Hara, 1971). **Parathemisto gaudichaudi** se alimenta de diversos organismos del plancton, variando su dieta con la estación, de modo que el contenido estomacal de estos Anfípodos informa sobre la composición del plancton en la región que habitan, y así se alimentan de Clupeidos, Ammodytidos, Copépodos, Eufáusidos, otros Anfípodos, Quetognatos e Hidromedusas.

Burukovskiy y Froyerman (1963) han estudiado la alimentación de varias especies de camarones, basándose en el aparato bucal y el contenido estomacal, y así han comprobado que **Penaeus aztecus, P. brasiliensis, P. duorarum,**

P. keratus se nutren de varias clases de peces, otros camarones, Eufáusidos, Anfípodos, cangrejos, Moluscos, Poliquetos y Equinodermos.

Las larvas de Crustáceos Decápodos, incluyendo las larvas de langsta se alimentan de otros Decápodos jóvenes (Weldon y Fowler, 1890) pececillos y pequeños Crustáceos (Steuer, 1910) y peces jóvenes (Bigelow 1926). Las larvas de **Homarus vulgaris** consumen larvas de otros Decápodos y Copépodos (Lebour, 1922), y las larvas Phyllosoma **(Palinurus vulgaris)** devoran ávidamente a larvas de **Lophius piscatorius** (Lebour, 1925) y Copépodos.

Se ha observado que el Poliqueto **Tomopteris helgolandicus** se alimenta de larvas y peces jóvenes, principalmente de **Clupea harengus** y otros organismos del plancton (Lebour, 1923).

El Cefalópodo **Octopus vulgaris** se alimenta de peces (Cort y Pérez-Gandaras 1973), y Burukovskyi y Floyerman (1973) incluyen además a otros Cefalópodos, Eufáusidos y demás Crustáceos en la dieta de estos Moluscos. M. W. Johnson (1942) describe el alimento y forma de capturar la presa que presenta **Paraoctopus apoliyon**, engullendo peces, camarones y otros animales, llegando a realizar 15 redadas copiosas de este tipo en sólo unos 25 minutos.

Illex conideti, I. illecebrosus, Todarotes sagittatus y **Loligo pealei** (Burukovskiy y Froyerman, 1973 se alimentan de peces, Eufáusidos, cangrejos y otros Cefalópodos.

Octopus vulgaris, Loligo vulgaris y **Sepia officinalis hierredda** aparecieron en gran abundancia en el Banco Sahara en 1966-1967, en un área que abarcaba desde 23°N hasta 25°N en una región con profundidades de unos 50 m frente al Shara Español (Crot y Pérez-Gándaras, 1973). Se observó que los Spáridos **Dentex dentex, D. canariensis, Pagrus pagrus** habían disminuido drásticamente en esa región desde 1960 debido a que se había venido practicando una pesca excesiva en estas poblaciones. Simultáneamente con esta desaparición de los Spáridos, se observó que las poblaciones de Cefalópodos aparecían en gran abundancia, y devoraban grandes cantidades de larvas de Spáridos. En otras épocas, cuando estos Spáridos eran muy abundantes en el Banco Sahara, las poblaciones de Cefalópodos estaban controladas por la actividad depredadora de los Spáridos. Se observó así mismo que en otras zonas próximas a esta región, donde las poblaciones de peces no han sido sometidas a una pesca excesiva, se mantiene un equilibrio entre las poblaciones de peces y Cefalópodos, de carácter semejante a la que existía antes en el Banco Sahara. De modo que lo que ahora sucede es, que las poblaciones de peces no pueden recuperarse debido al ataque depredador que ejercen los Cefalópodos, al devorar las larvas, y a su vez los peces no son suficientes para consumir Cefalópodos, así que éstos estarán sólo controlados por la escasez de alimento, ya que no existen peces en número suficiente para mantener reducida la producción de Cefalópodos, y por una pesca intensiva que precisamente está iniciándose en aquella región.

Hjort (en Murray y Hjort, 1912) explica que el calamar **Ommatostrephes todarus** persigue a los arenques devorando grandes cantidades de estos peces en el Mar de Noruega, y la abundancia de **O. sagittatus** juntamente con varias especies de medusas (Lucas y Henderson, 1937) coincidió con la desaparición de las poblaciones de arenque en la región de Shetland en 1931.

Filipova (1974) indica que en la dieta de los Cefalópodos, **Symplectoteuthis oualaniensis, S. luminosa, Ommatrephes bartani, O. pteropces** y **Todarotes angolensis,** procedentes del Atlántico e Indico, los peces ocupan el lugar principal seguidos por Crustáceos y otros Cefalópodos.

Los peces son también depredadores de peces jóvenes y larvas, pero este tema no será discutido aquí. Los peces adultos son animales nectónicos y este estudio trata estrictamente de la depredación en el reino del plancton.

Por todo lo expuesto se puede reconocer la magnitud de la devastación que afecta a las crías de los peces oceánicos, y por lo tanto deseo hacer énfasis sobre este tema para resaltar la necesidad de llevar a cabo más investigaciones relacionadas con depredación. Los valores específicos que se obtengan en estas investigaciones se podrán aplicar entonces a los cálculos correspondientes para determinar la abundancia de las poblaciones pesqueras y en consecuencia orientar con mayor precisión los varios aspectos de la pesca, su estrategia, conservación y la industria pesquera.

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LOS INDICADORES PLANCTONICOS: DISTRIBUCION BATIMETRICA DE ALGUNAS MEDUSAS

Angeles Alvariño

Resumen

El material estudiado corresponde a colectas de plancton efectuadas con redes BONGO de apertura y cierre automáticos, a lo largo de una serie de localidades frente a Monterrey y San Diego, California (EE.UU.), y Punta Eugenia, Baja California (México). Las colecciones de plancton se tomaron día y noche en cada posición, a ocho niveles de profundidad estratificados desde 600 metros hasta la superficie, durante el invierno, primavera, verano y otoño de 1969. Las localidades exploradas corresponden a tres zonas con características faunísticas, ecológicas y oceanográficas bien definidas, respectivamente bajo la influencia nórdica, el influjo de las aguas de componente norte y sur, y bajo la influencia de las aguas cálidas procedente de la región tropical del Pacífico oriental.

Las medusas batiales observadas en estas colecciones son, las Escifomedusas **Peryphylla periphylla** (Péron y Lesueur) 1809, **Atorella vanhoeffeni** Bigelow 1909, **Atolla wyvillei** Haeckel 1880, **Nausithoë punctata** Kölliker 1853, y las Hidromedusas batiales **Aegina citrea** Eschscholtz 1829, **Aeginura grimaldii** Maas 1904, **Calycopsis simulans** (Bigelow) 1909, **Chromatonema rubrum** Fewkes 1882, **Colobonema sericeum** Vanhoffen 1902, **Euphysora gigantea** Kramp 1957, **Halicreas minimum** Fewkes 1882, **Pantachogon haeckeli** Maas 1893.

Se discute la distribución tridimensional que presentan estas especies en relación con el período de captura (día y noche), la estación del año y las condiciones oceanográficas de la región, demostrando así su utilidad como indicadores planctónicos. También se incluyen datos distribucionales correspondientes a otros años para la misma región y se discuten en relación con la información pertinente publicada y las características ontogénicas que presentaba cada especie. Las Tablas incluyen el número de ejemplares (calculados para la duración de la pesca), sus respectivas tallas para cada estrato batial, hora, fecha, localidad, y para ambas redes BONGO (babor y estribor). La discusión está ilustrada con perfiles distribucionales para cada especie, para la serie de estaciones, día y noche, y épocas del año.

N. punctata, P. haeckeli, Ch. rubrum, se presentaron solamente en una localidad en diciembre. **Calycopsis simulans** aparecía en dos posiciones frente a Monterrey, en las colecciones de mayo. **Euphysora gigantea** (considerada hasta ahora una especie de aguas Antárticas) aparece representada por un solo ejemplar obtenido en septiembre de 1969 a 600-475 m de profundidad en la posición más oceánica ocupada frente a Punta Eugenia. Las demás especies de medusas seleccionadas para este estudio aparecían con amplia distribución en las aguas californianas.

Introducción

No existe mucha información sobre la distribución batimétrica de las Medusas, y en este trabajo me ocupo de las especies batipelágicas encontradas en las colecciones de plancton obtenidas en la región de California durante las cuatro estaciones de 1969.

Los datos obtenidos con estos estudios contribuyen a completar los conocimientos que se tienen de este grupo en cuanto a faunística, ecología, indicadores de condiciones hidrográficas etc. Russell (1970) establece que las Medusas desempeñan un papel muy importante en la economía del mar, ya que son organismos depredadores y competidores en la obtención de alimento, con los peces y otros animales de importancia comercial.

La serie de posiciones ocupadas durante los cruceros de 1969 en la región de California, corresponden a tres zonas con características particulares, frente a Monterrey, San Diego y Punta Eugenia. Estas zonas están influidas por las aguas de componente nórdica, aguas tropicales y la zona central (San Diego) que recibe la acción de ambas corrientes, norte y tropical.

Algunas especies de Medusas aparecen constantemente en las colecciones de plancton y son siempre abundantes, mientras que otras especies sólo se presentan en ciertas estaciones, y tampoco se observan todos los años.

La información publicada sobre la distribución batimétrica de las Medusas en la región de California (Alvariño, 1967) corresponde a las colecciones obtenidas frente a San Diego, California, con redes BONGO de cierre y apertura automáticos. En estas colecciones, las pescas de plancton abarcaron catorce estratos, desde unos 3.000 metros hasta 0 m de profundidad. Algunas de las especies de Medusas batipelágicas observadas en las colecciones de 1969, aparecían también en los estudios publicados (Alvariño, 1967) correspondientes a las colecciones obtenidas del 27 de agosto al 8 de septiembre de 1965.

Las Medusas batipelágicas observadas en 1969, Hidromedusas y Escifomedusas, comprenden las siguientes Familias y especies: La Familia Aeginidae aparece representada por las especies **Aegina citrea** y Aeginura grimaldii, la Familia Calcycopsidaeae por la especie **Calycopsis simulans,** Rhopalonemidae por las especies **Colobonema sericeum** y **Pantachogon haeckeli,** Halicreatidae por **Halicreas minimum,** para la familia Tubulariidae se encontró **Euphysora gigantea,** Tiarannidae con la especie **Chromatonema rubrum,** Attollidae con **Atolla wyvillei,** Atorellidae con **Atorella vanhoeffeni,** Periphyllidae con **Periphylla periphylla,** y Nausithodaë con **Nausithoe punctata.**

Algunas de estas especies se han observado previamente en la región de California o en zonas adyacentes (Alvariño, 1967, 1969, 1972, 197 ; Bigelow 1909, 1940; Kramp 1959, 1965, 1968; Maas, 1897).

Este trabajo incluye tablas con la distribución cuantitativa de las especies, con la fecha y hora de captura, y el número de individuos colectados en cada red (babor y estribor) que constituyen el par BONGO. La discusión sobre la distribución de las especies se ilustra con perfiles batimétricos que se insertan comprendiendo la distribución diurna y nocturna de las especies en cada línea de estaciones ocupadas en la región de California durante los cruceros realizados en las cuatro estaciones del año 1969.

Métodos

Las colecciones de plancton analizadas corresponden a los cruceros del proyecto CalCOFI (Cooperativa de Investigaciones de Pesca Oceánica del Estado de California) realizadas durante las cuatro estaciones de 1969; febrero-marzo (crucero 6202-03), mayo-junio (6905-06), agosto-septiembre (6908-09), noviembre-diciembre (6911-12).

El plancton ha sido colectado con redes BONGO de apertura y cierre automático. Las posiciones ocupadas se extienden por la región de California y Baja California, en estaciones localizadas a lo largo de las líneas 70, 90 y 120, del plan de estaciones CalCOFI, respectivamente frente a Monterrey, San Diego y Punta Eugenia.

Las pescas de plancton se efectuaron de día y de noche en las mismas localidades y profundidades, coincidiendo aproximadamente con el período de mediodía y medianoche. Las pescas se efectuaron a ocho niveles de profundidad, desde 600 metros hasta la superficie, distribuidas en los siguientes intervalos, 600-475, 475-350, 350-225, 225-100, 100-75, 75-50, 50-25, 25-0 metros, para la primavera verano y otoño, mientras que durante el invierno las colectas sólo alcanzaron a los 300 metros de profundidad aproximadamente.

La velocidad del arrastre estaba calculada para que en cada pesca las redes (babor y estribor) combinadas filtrasen un total de 1000 m^3 de agua. Sin embargo, la velocidad de arrastre es distinta, en los intervalos de 125 m (que corresponden a las profundidades de 600 a 100 metros) y los intervalos de 25 m (de los 100 a los 0 metros de profundidad). Para comparar los datos cuantitativos obtenidos en los estratos a intervalos de 125 m y 25 m se precisa calibrar los resultados, mediante la fórmula:

$$N = \frac{n\ (\text{profundidad de apertura-profundidad de cierre})}{25}$$

N = Número total de individuos.
n = Número de ejemplares en las redes babor y estribor.

Las Medusas Batipelágicas de California

Las especies de Medusas (Hidromedusas y Escifomedusas) obtenidas durante los cruceros de 1969 habitando los lechos bati- y mesopelágicos de la región de California y Baja California, corresponden a las familias Aeginidae, Rhopalonematidae, Halicreatidae, Tiarannidae, Calycopsidae, Tubulariidae, Atollidae, Atorellidae, Periphyllidae y Nausithoidae en las que se incluyen las siguientes especies: **Aegina citrea** Eschscholtz 1829, **Aeginura grimaldii** Maas 1904, **Colobonema sericeum** Vanhöffen 1902, **Halicreas minimum** Fewkes 1882, **Pantachogon haeckeli** Maas 1893, **Chromatonema rubrum** Fewkes 1882, **Calycopsis simulans** (Bigelow) 1909, **Euphysora gigantea** Kramp 1957, **Atolla wyvillei** Haeckel 1880, **Atorella vanhoeffeni** Bigelow 1909, **Periphylla periphylla** (Péron y Lesueur) 1809, **Nausithoë punctata** (Kölliker) 1853.

La serie de posiciones ocupadas frente a Monterrey, San Diego y Punta Eugenia, en aguas de California y Baja California, corresponden a tres zonas con características ecológicas y faunísticas bastante bien definidas. La zona de Monterrey está directamente influida por las aguas nórdicas, la zona de San Diego recibe la influencia atenuada de las aguas nórdicas y de las cálidas procedentes del Pacífico tropical oriental, y la zona de Punta Eungenia está bajo la influencia directa de las aguas tropicales que avanzan hasta estas latitudes.

Las pescas de plancton durante los cruceros de 1969 alcanzaron solamente hasta los 600 metros de profundidad, como se ha indicado, y por lo tanto el número de especies colectadas, así como el tamaño de los ejemplares obtenidos indican que los individuos capturados corresponden a los bordes de unos centros de población que habitan lechos más profundos que los alcanzados por las redes de plancton. Así las Medusas bati- y mesopelágicas obtenidas durante los cruceros de 1969 no presentan en general una distribución uniforme, sino que aparecen irregularmente distribuidas, esparcidas por la región de las Californias. Esta distribución puede estar en parte influida por la dinámica de las aguas en las zonas meso- y batipelágicas, y por fenómenos de sugerencias de aguas profundas.

La distribución cuantitativa de las Medusas se presentan en Tablas para cada especie, incluyendo además la fecha y hora de captura, profundidad y número de individuos en ambas redes y en su totalidad, calculado con arreglo a la fórmula arriba mencionada.

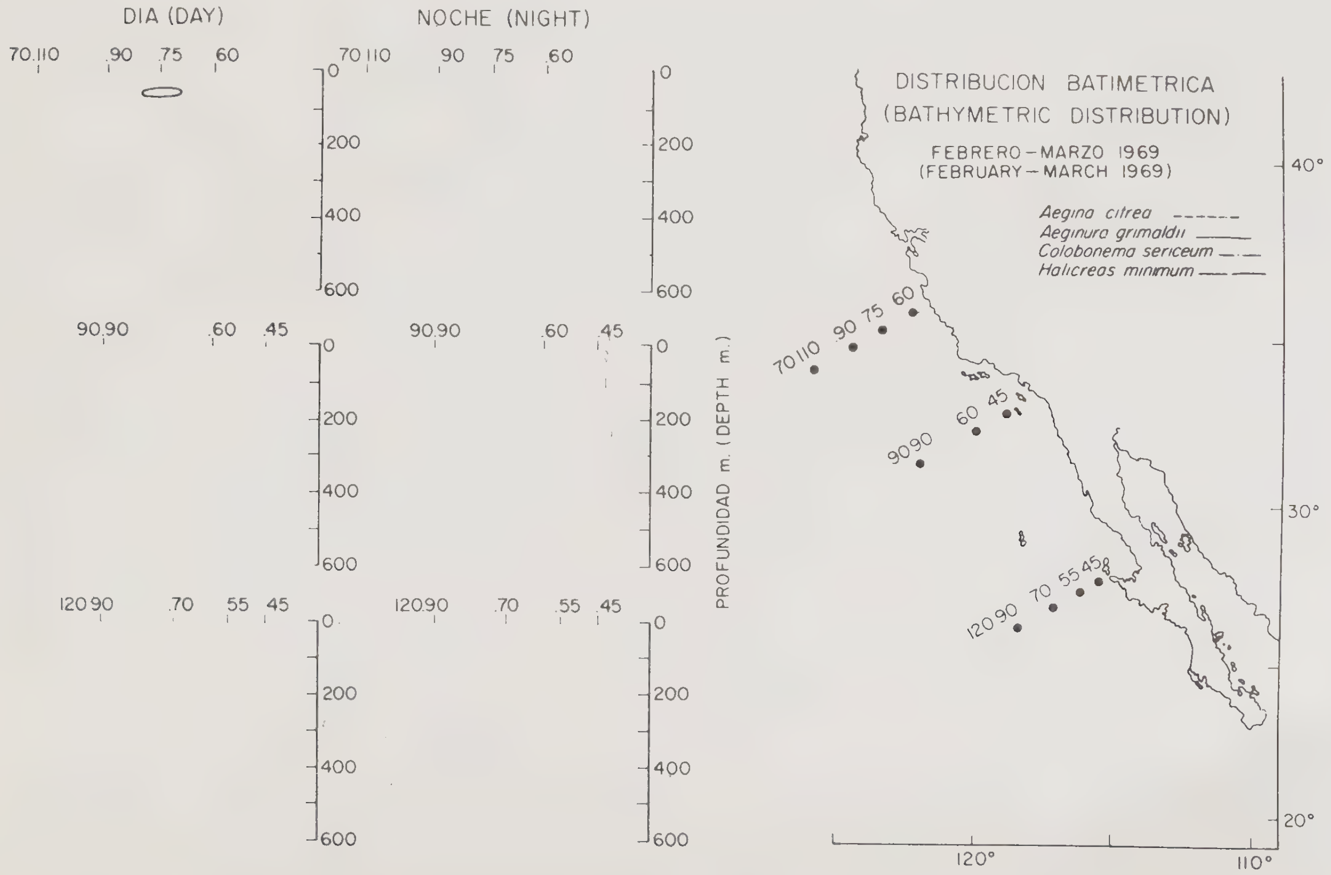
La distribución de cada especie se presenta en los perfiles batimétricos correspondientes a las pescas de día y de noche, y para las cuatro estaciones del año.

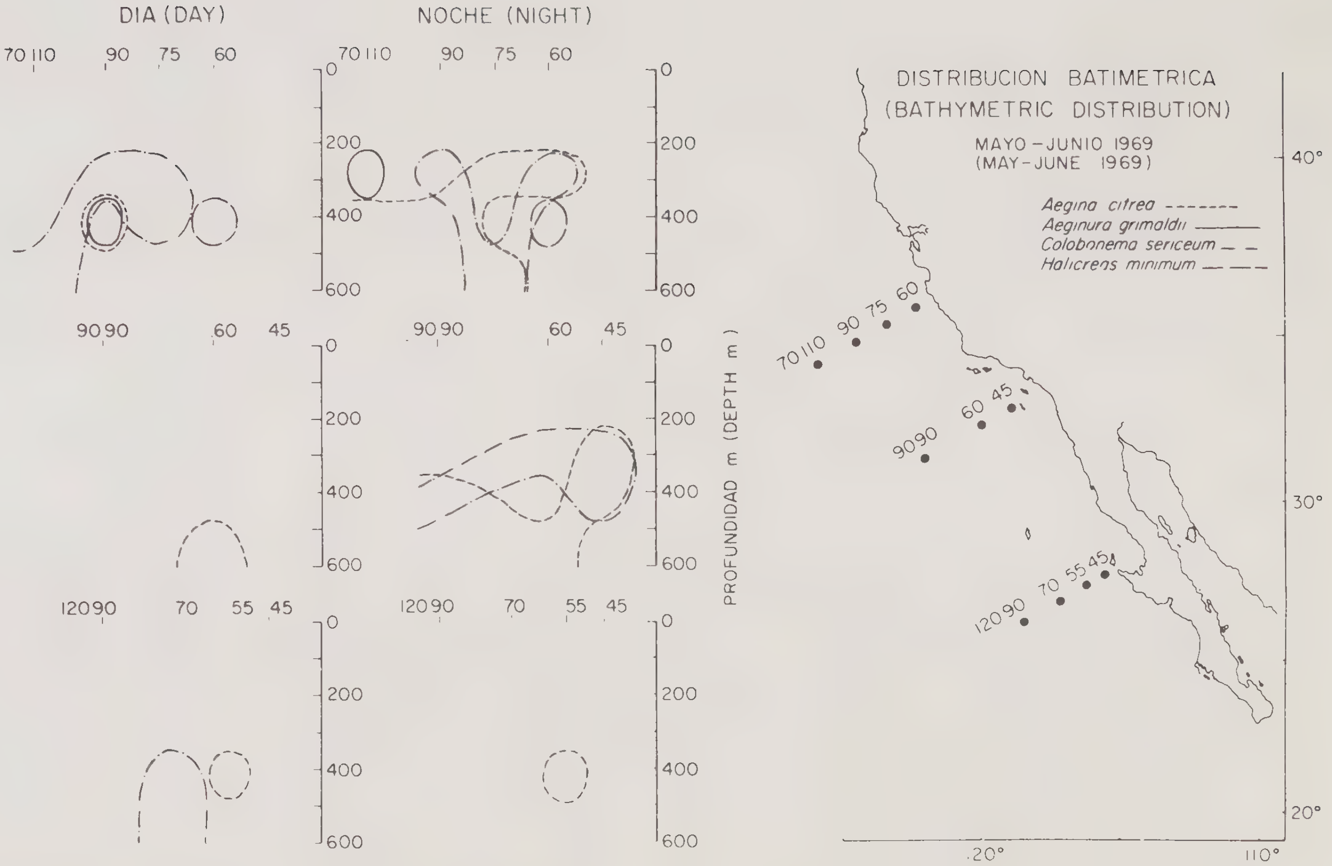
Aegina citrea es una especie meso-batipelágica con amplia distribución geográfica en el Atlántico, Indico y Pacífico. Las observaciones previas sobre la distribución batimétrica de esta especie en la región de California (Alvariño, 1967) correspondían a los 1700-1500 m de profundidad para las pescas nocturnas, y no se presentaba en las pescas diurnas. Bigelow (1913) observó a esta especies en California, frente a Costa Rica (Bigelow, 1940), y en la región de Panamá (Kramp, 1959). También ha sido observada en aguas de California (Alvariño, 197) en las colecciones mensuales correspondientes al programa CalCOFI, obtenidas en pescas oblicuas desde unos 140 m de profundidad hasta 0 m, en enero de 1961, en las estaciones 60.100 y 90.80 respectivamente en la zona de San Francisco y San Diego. La presencia de **A. citrea** en tales lechos cercanos a la superficie oceánica indica que en dichas localidades se estaban produciendo fenómenos de surgencia.

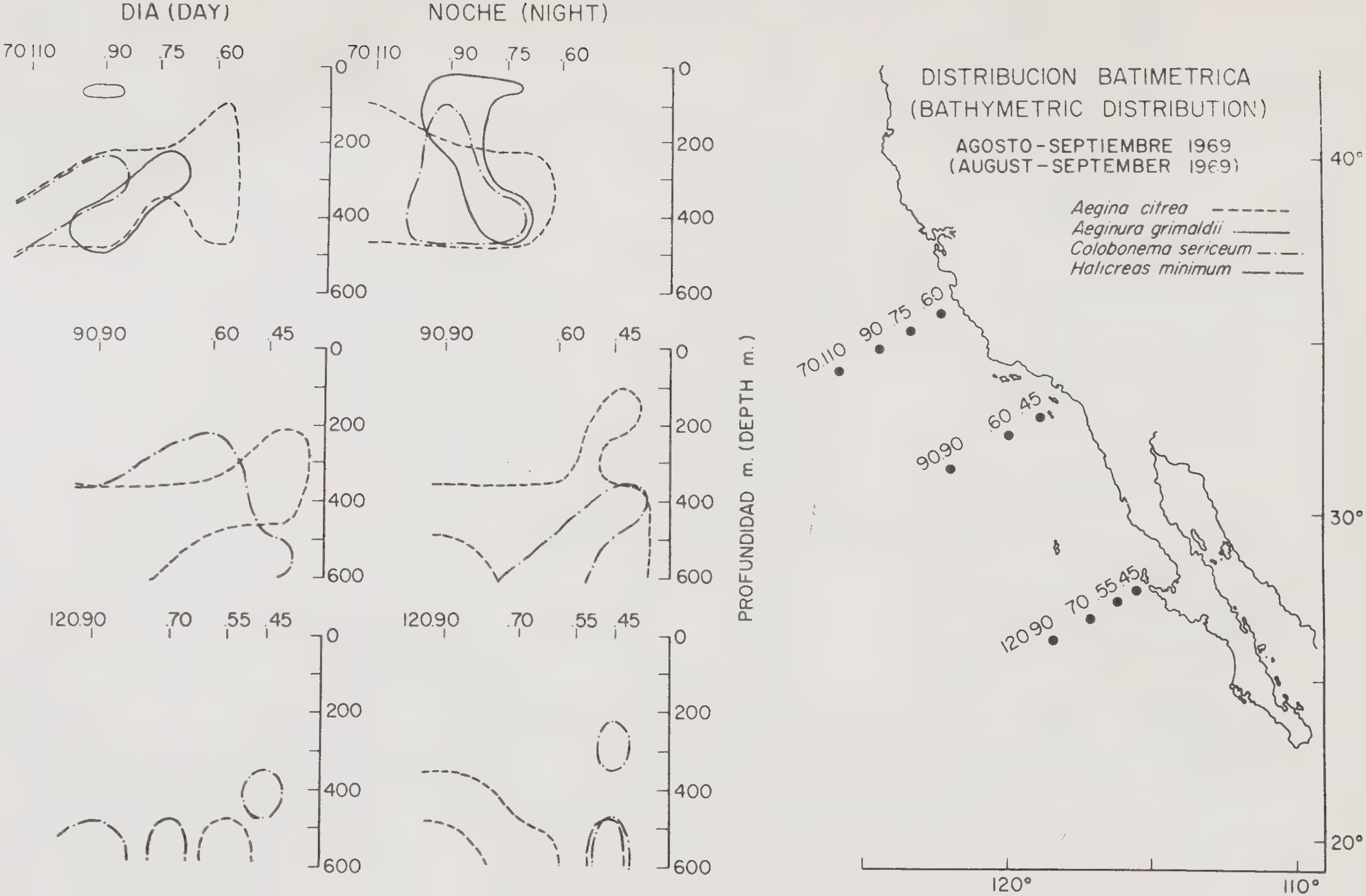
En las colecciones de 1969 de que se ocupa el presente trabajo, **A. citrea** no aparecía en las muestras correspondientes al invierno (6902-03), debido a que durante estos cruceros las redes de plancton no alcanzaron en sus pescas más de los 300 m de profundidad. En la primavera de 1969, **A. citrea** aparecía frente a Monterrey, San Diego y Punta Eugenia, y en general con mayor abundancia de noche que de día. Así, frente a Monterrey aparecía de día a los 475-350 m en una sola estación (70.90.), y de noche en las estaciones de esa zona extendiéndose muchas millas mar afuera, ocupando desde los 600-225 m de profundidad, apareciendo en las localidades más cercanas a la costa a niveles menos profundos (70.100, 70.90, 70.75, 70.60). Frente a San Diego, se encontró solamente en una estación a 600-475 m de día (Estación 90.60), y a 600-350 m, 600-475 m y 475-225 m respectivamente en las Estaciones 90.90, 90.60, 90.45. En las localidades costeras esta especie aparecía a niveles menos profundos. Frente a Punta Eugenia, se encontró de día y noche a los 475-350 m de profundidad en la Estación 120.55. Fig. 2.

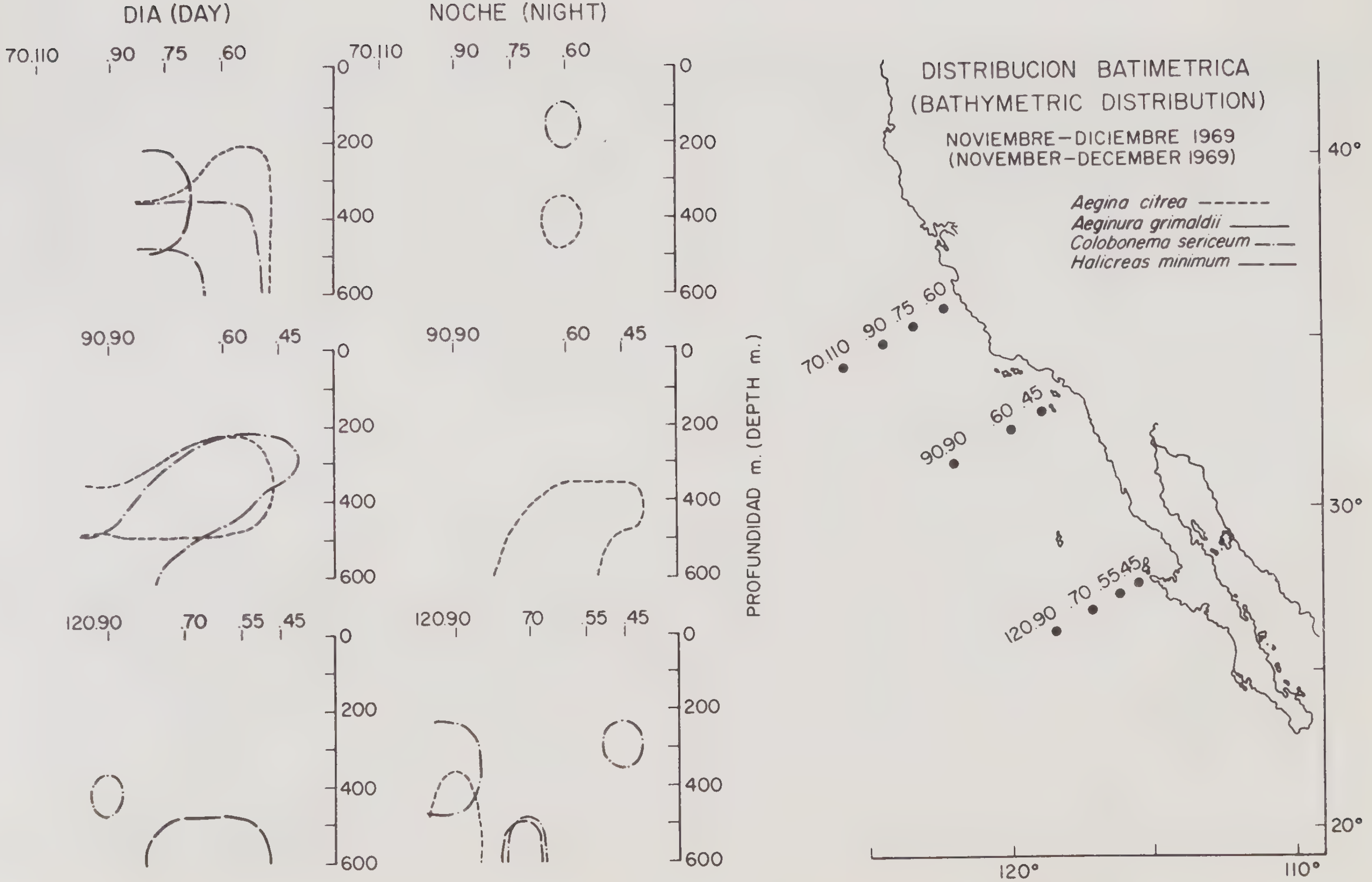
En el verano, **A. citrea** se extendía frente a Monterrey de los 475-350 m, 475-225 m, 350-225 m y 475-100 respectivamente en las Estaciones 70.100, 70.90, 70.75 y 70.60, durante el día, y a 475-100 en la Estación 70.100. y a los 475-225 m en las Estaciones 70.90 y 70.75 durante las pescas nocturnas. Frente a San Diego apareció de día a 600-350 m, 475-350, 475-225, respectivamente en las Estaciones 90.90, 90.60, 90.45, y de noche a los 475-350, 600-350, 600-350 y 225-100 respectivamente en las posiciones 90.90, 90.60 y 90.45. Frente a Punta Eugenia sólo apareció de día en la estación más cercana a la costa en los 600-475 m de profundidad, y de noche en las localidades alejadas de la costa (120.90 y 120.70) a profundidades respectivamente de 475-350 m y 600-475 m. También durante esta estación, la especie tendía a ocupar lechos menos profundos en las localidades más próximas a la costa.

En el otoño, **A. citrea** aparecía frente a Monterrey a los 600-350 m y 600-225 m de profundidad de día en las Estaciones 70.75 y 70.60, y de noche solamente en una localidad (Estación 70.60) a los 475-350 m de profundidad. Frente a San Diego aparecía de día a los 465-350 m, y 475-225 m en las localidades 90.90 y 90.60, y de noche a los 600-350 m en las Estaciones 90.60 y 90.45. En la zona de Punta Eugenia se observó solamente de noche a 475-225 m y únicamente en la Estación más oceánica (120.90). Fig. 4.


DIA (DAY)
NOCHE (NIGHT)
70.110
90
75
60
90.90
60
45
120.90
70
55
45
0
200
400
600
PROFUNDIDAD m. (DEPTH m.)
DISTRIBUCION BATIMETRICA
(BATHYMETRIC DISTRIBUTION)
FEBRERO–MARZO 1969
(FEBRUARY–MARCH 1969)
Aegina citrea
Aeginura grimaldii
Colobonema sericeum
Halicreas minimum
40°
30°
20°
120°
110°


DISTRIBUCION BATIMETRICA
(BATHYMETRIC DISTRIBUTION)
MAYO-JUNIO 1969
(MAY-JUNE 1969)
Aegina citrea -------
Aeginura grimaldii ———
Colobonema sericeum — —
Halicreas minimum — ——
DIA (DAY)
NOCHE (NIGHT)
70 110
90
75
60
9090
60
45
12090
70
55
45
0
200
400
600
PROFUNDIDAD m (DEPTH m)
70110
90
75
60
9090
60 45
12090
70 55 45
40°
30°
20°
20°
110°


DIA (DAY)
NOCHE (NIGHT)
DISTRIBUCION BATIMETRICA
(BATHYMETRIC DISTRIBUTION)
AGOSTO-SEPTIEMBRE 1969
(AUGUST-SEPTEMBER 1969)
Aegina citrea
Aeginura grimaldii
Colobonema sericeum
Halicreas minimum
PROFUNDIDAD m. (DEPTH m.)
70.110
90
75
60
90.90
60
45
120.90
70
55
45
0
200
400
600
40°
30°
20°
120°
110°


DIA (DAY)
NOCHE (NIGHT)
70.110
90
75
60
90.90
45
120.90
70
55
0
200
400
600
PROFUNDIDAD m. (DEPTH m.)
DISTRIBUCION BATIMETRICA
(BATHYMETRIC DISTRIBUTION)
NOVIEMBRE–DICIEMBRE 1969
(NOVEMBER–DECEMBER 1969)
Aegina citrea
Aeginura grimaldii
Colobonema sericeum
Halicreas minimum
40°
30°
20°
120°
110°

Aeginura grimaldi es otra medusa de aguas profundas, y Bigelow (1938) considera que la máxima concentración de individuos ocupan los 1600-1000 m de profundidad, aunque Thiel (1936) obtuvo individuos jóvenes en estratos menos profundos. Bigelow (1940) obtuvo ejemplares de **A. grimaldi** en la región de Panamá. Alvariño (197—) observó esta especie en aguas de California en las colecciones mensuales del programa CalCOFI en pescas desde los 140 m a la superficie oceánica, encontrándose en mayo de 1954, en las Estaciones 97.45, 100.80, 100.50, 100.35, 103.70, 107.80, en enero de 1958 en las Estaciones 93.70, 143.50 157.100, y en enero de 1961 en las Estaciones 60.100 y 60.200. Es seguro que la presencia de **A. grimaldi** en los estratos de 140-0 m de profundidad indica que procesos de surgencia tenían lugar en las localidades ocupadas por dicha especie.

En las colecciones de plancton tomadas a varios estratos de profundidad durante 1969, **A. grimaldii** aparecía en febrero en la zona de Monterrey a 75-50 m durante el día, Estación 70.75. Este dato puede considerarse como una indicación de que se habían producido algunas surgencia en esa localidad, y los individuos de **A. grimaldii** que quedaron en esos niveles poco profundos eran un remanente de la población transportada durante el afloramiento. Fig. 1.

En la primavera se observó **A. grimaldi** en la zona de Monterrey a 475-350 m de día en la Estación 70.90, y a 350-225 m de noche en la Estación 70.100. Fig. 2.

En el verano aparecía **A. grimaldii** frente a Monterrey a 475-350 m, 75-50 m en la Estación 70.90 y a 350-225 en la Estación 70.75 durante las pescas de día, y a 225-50 m (Estación 70.90) y 475-350, 75-50 de noche en la Estación 70.75. También podía considerarse que aquí se estaban produciendo fenómenos de surgencia de aguas profundas. Esta especie no se observó en las localidades más meridionales ocupadas frente a San Diego y Punta Eugenia, Fig. 3. Durante el verano y es posible que las poblaciones de **A. grimaldii** se encontrarían entonces a niveles más bajos que los alcanzados por las redes de plancton. Tampoco se presentó esta especie durante los cruceros del otoño de 1969.

Los ejemplares de **A. grimaldii** obtenidos en los cruceros de 1969 alcanzaban unos 45 mm de diámetro.

Colobonema sericeum se extiende por las aguas profundas del Atlántico, Indico y Pacífico. Esta especie ha sido previamente observada en las regiones adyacentes a California, así en Panamá (Bigelow, 1959; Kramp, 1959; Alvariño, 1972) y en el Mar de Cortés (Alvarño, 1969). En la región de California (Alvariño, 197—) ha sido observada en las colecciones mensuales del Programa CalCOFI, en pescas oblicuas desde 140 m hasta la superficie, en los cruceros de abril de 1958 en las Estaciones 123.55, 123.40, 127.32, 130.55, 133.80, 137.89, 137.70, 137.50, 137.45. Estas observaciones indican que en dichas localidades se producían surgencias de aguas profundas.

C. sericeum ha sido observada de día y de noche frente a San Diego, California (Alvariño, 1967) en el verano de 1965 a 500-400 m de profundidad.

En las colecciones que aquí se estudian correspondiente a 1969 m

C. sericeum aparecía en la primavera, verano y otoño, pero estaba ausente de las colecciones de invierno en 1969, debido probablemente a que la especie habitaba estratos más profundos que los alcanzados por las redes de plancton durante los cruceros realizados en esta estación, en que solamente se llegó a unos 300 m de profundidad.

En la primavera de 1969, **C. sericeum** aparecía frente a Monterrey a 600-475 m, 350-225 m, 475-225 m respectivamente en las localidades 70.100, 70.90, 70.75, durante el día, y de noche a los 350-225, 600.475 m y 350-225 m, respectivamente en las Estaciones 70.90, 70.75, 70.60. Frente a San Diego sólo se obtuvo de noche a los 475-350 m 350-225, 475-225 m respectivamente en las localidades 90.90, 90.60 y 90.45. En la zona de Punta Eugenia sólo aparecía de día a los 600.350 m en la Estación 120.70. Fig. 2.

En el verano de 1969, **C. sericeum** aparecía frente a Monterrey de los 475-350 m 350-225 m de día en las Estaciones 70.100 y 70.90, y a los 475-100, 475-350 de noche en las Estaciones 70-90 y 70.75. Frente a San Diego se presentaba con mayor frecuencia de día que de noche, a los 475-350 m, 600-225 m y 600.475 m de día en las localidades 90.90, 90.60, 90.45, y de noche solamente en los 600.475 y 475-350 m de profundidad en las Estaciones 90.60 y 90.45; mientras que en la zona de Punta Eugenia aparecía a 600-475 m y 475-350 m de día en las Estaciones 120.90 y 120.45, y de noche a los 600.475 y 350-225 m en la Estación más costera, 120.45. Fig. 3.

En el otoño de 1969, **C. sericeum** era también algo más frecuente de día que de noche. Así en la zona de Monterrey aparecía de día a 475-350 m y 600-350 m de profundidad en las Estaciones 70.75 y 70.60, y de noche se encontró en una sola localidad (70.60) a los 225.10 m de profundidad. Frente a San Diego sólo ocurría de día a 600-475, 475-350 y 350-225 m de profundidad en las Estaciones 90.90, 90.70 90,45, apareciendo en lechos más superficiales en las localidades más costeras y a mayores profundidades en las oceánicas. Frente a Punta Eugenia era sin embargo más abundante de noche que de día, y así durante el día sólo apareció a 475-350 m en la estación más alejada de la costa (Estación 120.90), y de noche se presentó en casi todas las Estaciones ocupadas oscilando su distribución en profundidad entre 475-225 m, 600-475 m y 350-225 m, respectivamente desde alta mar hasta la zona nerítica (Estaciones 120.90, 120.55, 120.45), observándose así mismo en niveles menos profundos en las localidades más cercanas a la región nerítica. Fig. 4.

Halicreas minimum es una especie ampliamente distribuida por los Océanos Atlántico, Indico y Pacífico. Bigelow (1940), Mayor (1910) la citan para el Pacífico trópico-oriental, y Alvariño (1967) lo menciona frente a San Diego denominada bajo la sinonimia **H. papillosum** Vanhöffen 1902, a profundidades entre 2.000 m a los 400 m de profundidad durante las pescas de día y a más de 2.000 m de profundidad durante las colectas nocturnas. Alvariño (197—) ha observado a esta especie en los cruceros mensuales, en arrastres oblicuos desde 140 m de profundidad hasta la superficie, correspondientes al mes de abril de 1958 en las Estaciones 93.55 y 103.60, y en octubre de 1958 en la Estación 83.70. Estos datos pueden considerarse como un indicio de proecsos de surgencia en esas localidades.

H. minimum ha sido observada en las colecciones aquí estudiadas para 1969, solamente en los cruceros de mayo, septiembre, noviembre y diciembre, y aparecía únicamente en los lechos más profundos alcanzados por las pescas. En mayo se observó frente a Monterrey a los 475-350 m en la Estación 70.60 durante las colectas de día, y de noche. En septiembre aparecía frente a Punta Eugenia a los 600-475 m de profundidad durante el día en la Estación 120.70, y de noche a la misma profundidad (600-475 m) pero en la Estación más nerítica (120.45).

En el otoño aparecía **H. minimum** con mayor frecuencia de día que de noche, presentándose en la zona de Monterrey a los 475-225 m de profundidad en la Estación 70.75 durante las pescas de día, y frente a Punta Eugenia a los 600.475 m de profundidad (Estaciones 120.70 y 120.55) tanto de día como de noche (a la misma profundidad, 600-475 m en la Estación 120.70). **H. minimum** no se obtuvo frente a San Diego en las colecciones de otoño. Figs. 2, 3, 4.

Pantachogon haeckeli presenta una amplia distribución por las aguas profundas del Atlántico, Indico y Pacífico. Los ejemplares colectados en las muestras correspondientes a 1969 presentaban tallas oscilando entre 12 mm hasta 15 mm de altura. **P. haeckeli** apareció solamente en una localidad frente a San Diego en diciembre (Estación 90.60) a 600.475 m de profundidad durante una pesca nocturna. Esta es la primera vez que **P. haeckeli** se observa en aguas californianas.

Chromatonema rubrum ha sido observada previamente en el Golfo de Panamá (Kramp, 1959). Alvariño (197) observó esta especie en las colecciones mensuales del Programa CalCOFI, en pescas desde 140 m hasta 0 m en la Estación 60.80 (en la zona de San Francisco) durante mayo de 1958. En las colecciones de 1969 aparecía en la Estación 90.90 a 475-350 m de profundidad en una pesca nocturna durante el mes de diciembre. Los ejemplares colectados alcanzaban unos 27 mm de diámetro y unos 22 mm de altura.

Calycopsis simulans es una especie previamente señalada por Bigelow (1909) para la región de Panamá, y en el Pacífico trópico oriental (Bigelow, 1913). Durante las colecciones de que se ocupa el presente trabajo, **C. simulans** aparecía únicamente en dos posiciones durante mayo de 1969. Frente a Monterrey (Estaciones 70.90 y 70.75) en colectas realizadas de día, respectivamente a las profundidades de 475-350 m (10 individuos) y a 350-225 m (5 ejemplares). Y en la Estación 90.30 en junio de 1958.

Euphysora gigantea es una Medusa que previamente ha sido observada únicamente en la región Antártica (Kramp, 1957). En las colecciones que se estudian en este trabajo, apareció un ejemplar de unos 26 mm de diámetro, cuyas características concuerdan exactamente con la descripción de Kramp (1957) para esta especie (globular, jelly very thick, bell cavity narrow with only one tentacle long and thin, carrying several bifurcated lateral branches separated by long inter vals). El ejemplar encontrado en California aparecía frente a Punta Eugenia (Estación 120.90) durante septiembre de 1969 en una colecta de plancton realizada de noche a 600-475 m de profundidad. Es posible que esta especie tenga una distribución más amplia en las aguas profundas de los océanos que la que aparece en la literatura, así la observación en aguas de Baja California es un indicio de que su distribución no está restringida a la región Antártica.

A continuación se presenta la distribución batimétrica de las Escifomedusas observadas en aguas de California y Baja California durante las cuatro Estaciones de 1969.

Atolla wyvillei es una Medusa batial oceánica que ocupa una mayor densidad de población en los estratos de 1500 a 500 m de profundidad, y en áreas de surgencias sus poblaciones pueden alcanzar niveles menos profundos en el océano (Browne, 1910, Broch, 1913, Stiasny, 1934, Kramp, 1969). Mass (1897) observó esta especie en el Golfo de Panamá, Mayor (1910) en la región de Panamá y las costas de América Central, Bigelow (1913) la cita en la región de San Francisco, Bigelow (1940) en el Pacífico trópico oriental extendiéndose desde Costa Rica hasta Colombia, Alvariño (1969) la ha observado en el Mar de Cortés. En California frente a San Diego, en pescas desde 1700-250 m de profundidad durante la noche, y a 3.000-2500 m hasta los 300 m de profundidad de día (Alvariño, 1967). En las colecciones del Programa CalCOFI correspondientes a pescas oblicuas desde 140 m hasta la superficie, esta especie aparecía (Alvariño, 197—) en la Estación 67.100 (en las inmediaciones de San Francisco) en octubre de 1958.

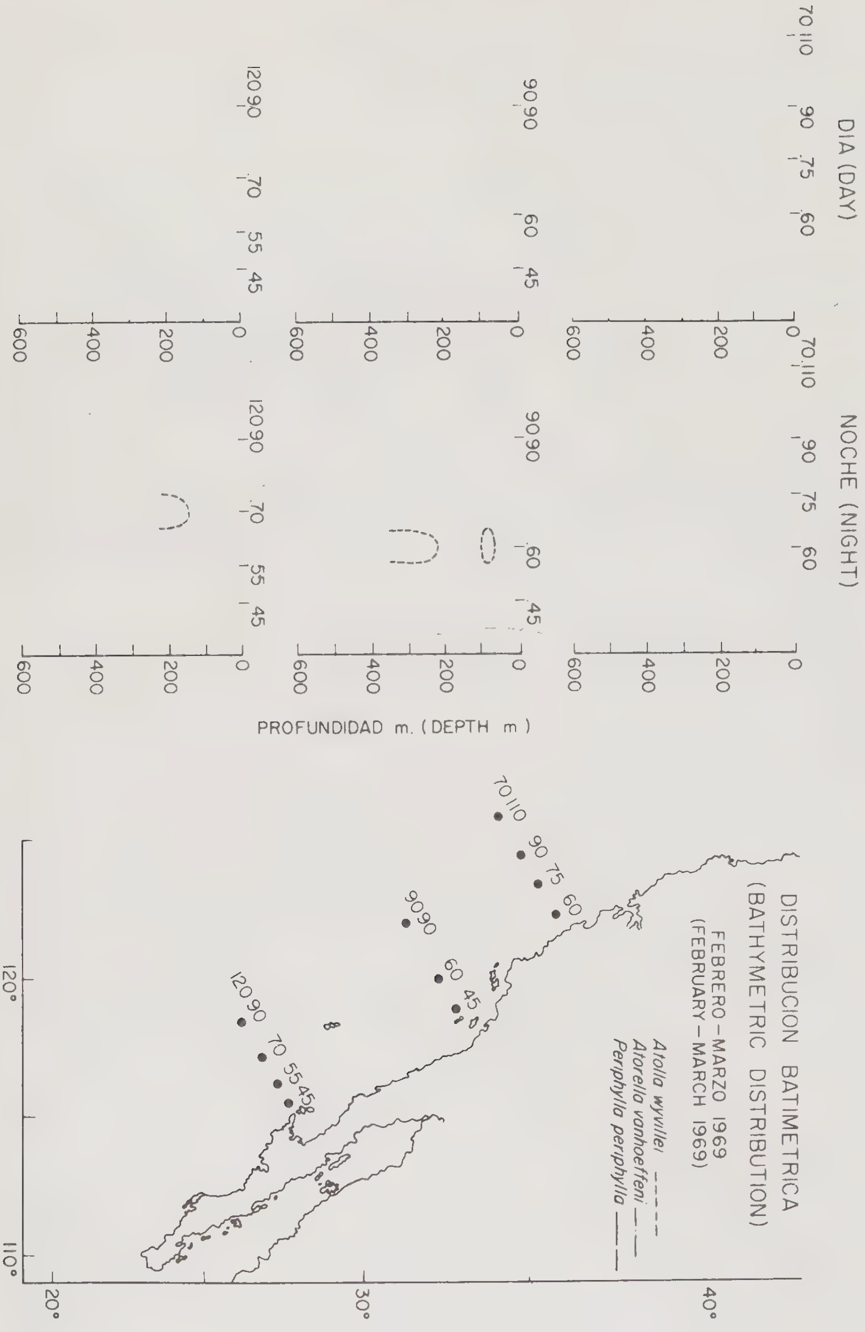
A. wyvillei no se encontró en las localidades ocupadas frente a Monterrey en febrero de 1969, pero se observó en la zona de San Diego únicamente a 350-225 y 100-75 en la Estación 90.60 durante la noche, y frente a Punta Eugenia se encontró también de noche a 200.150 m de profundidad en la Estación 120.70. Fig. 5.

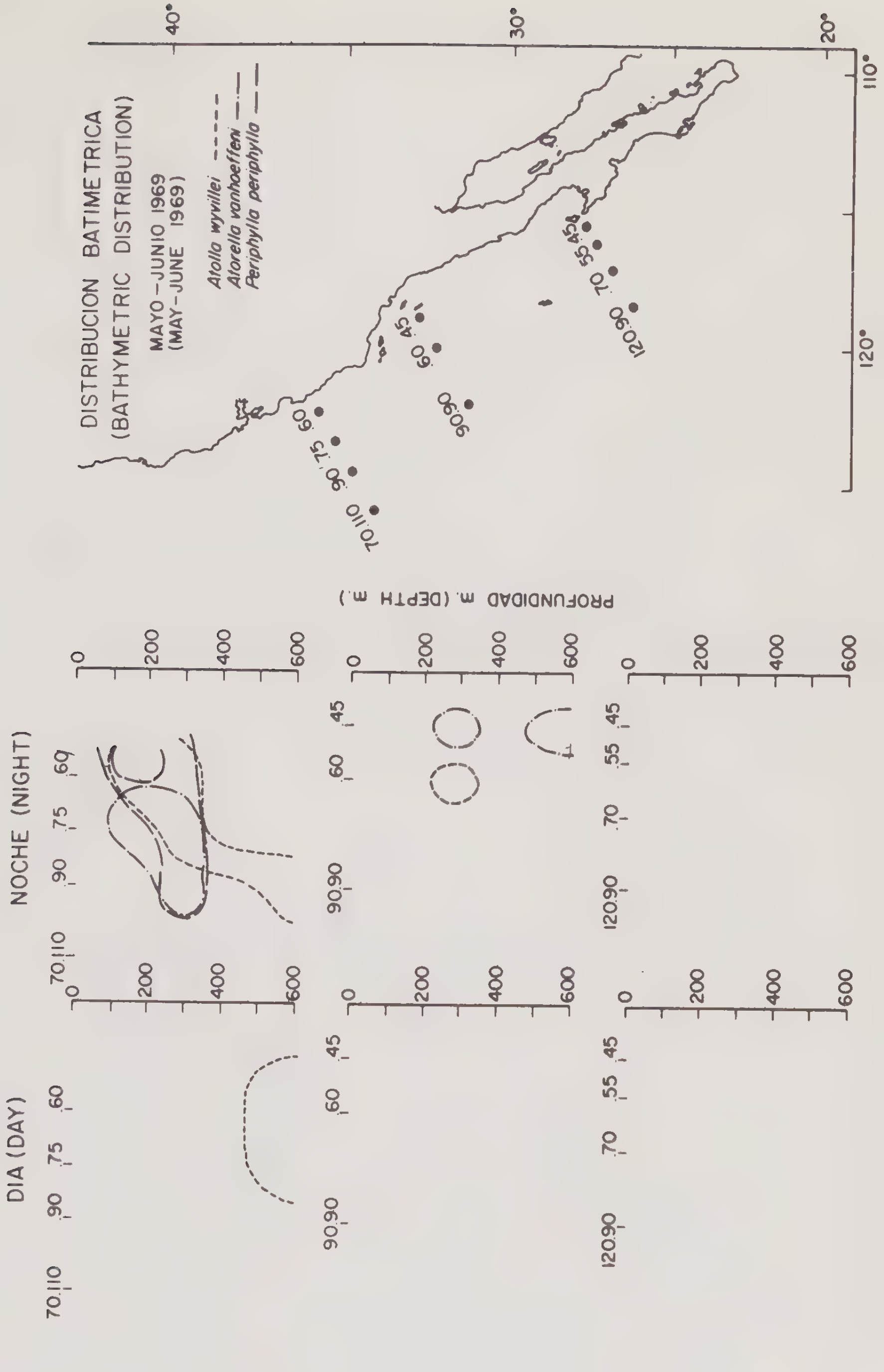
A. wyvillei se observó durante la primavera de 1969 en la zona de Monterrey a 600-475 m de profundidad durante el día en las Estaciones 70.75 y 70.60, y de noche; a 600-475, 350-225, 350-100 en las Estaciones 90.90, 90.75 90.60 frente a San Diego durante el día y a 350-225 m de profundidad en la Estación 90.60 de noche, no observándose en la región de Baja California, frente a Punta Eugenia. Fig. 6.

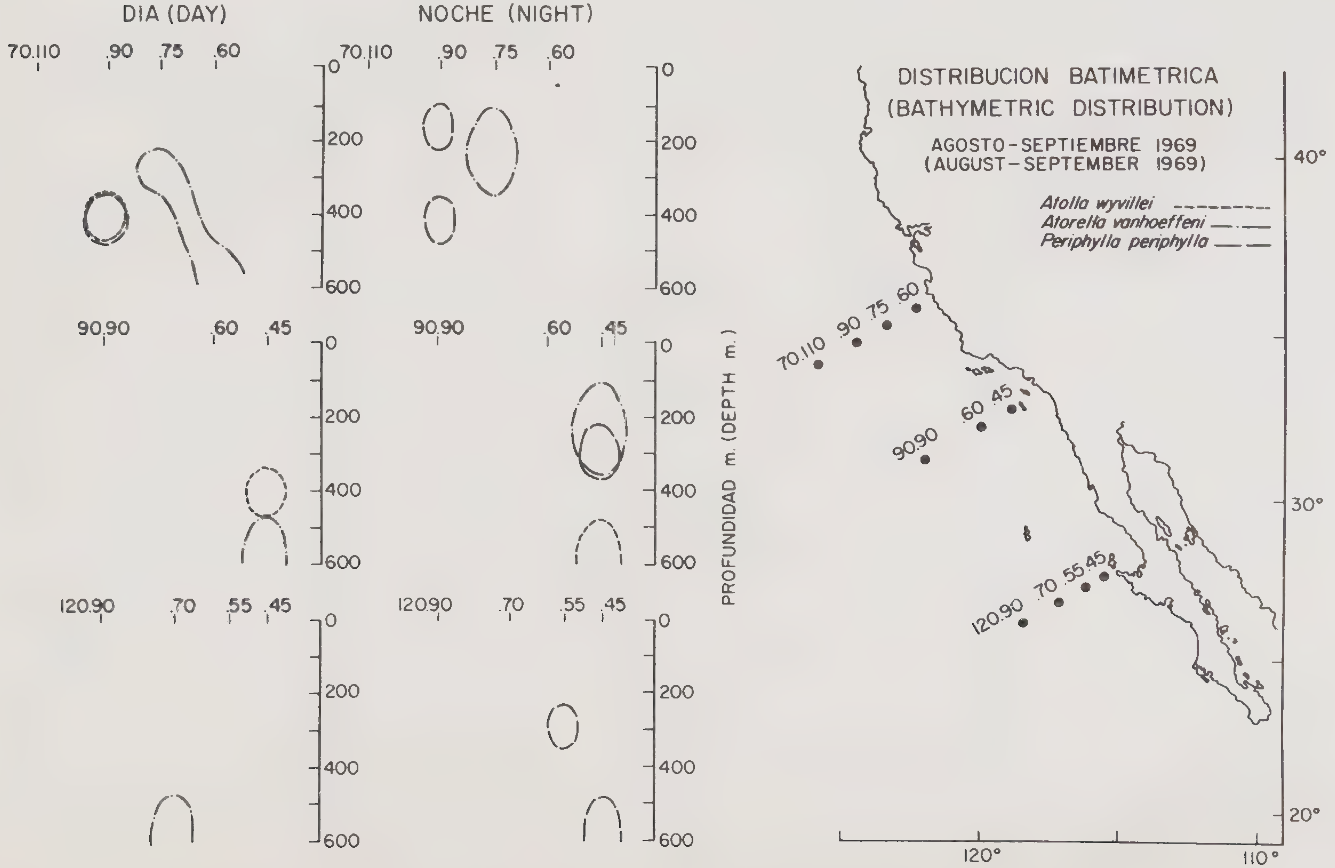
En el verano de 1969, aparecía **A. wyvillei** frente a Monterrey solamente a 475-350 m en la Estación 70.90 durante el día, y frente a San Diego a 475-350 m de profundidad en la Estación 90.45 de día, y de noche en la misma localidad a 600.475 m de profundidad, sin encontrarse en los estratos explorados frente a Punta Eugenia, donde posiblemente aparece a profundidades mayores que las investigaciones durante estos cruceros. Fig. 7.

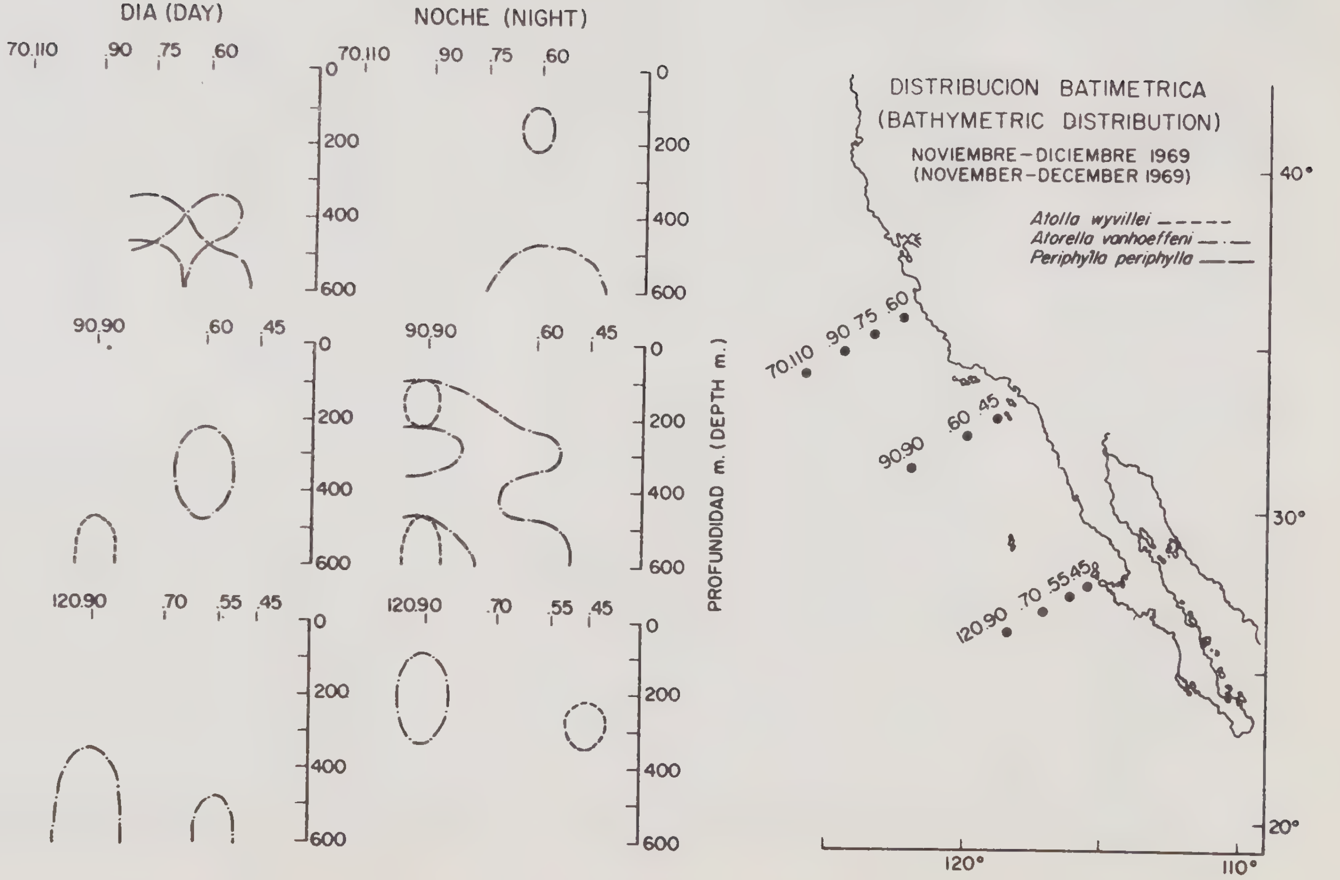
A. wyvillei no aparecía en el otoño de 1969 en la región de Monterrey, al menos en las profundidades estudiadas, y se observó en la zona de San Diego a 600-475 m en la Estación 90.90 durante las pescas diurnas, y en la misma Estación pero a los 600-475, y 225-100 m en las pescas nocturnas. En la región de Punta Eugenia aparecía solamente de noche a 350-225 m de profundidad en la Estación más cercana a la costa, 120.45. Fig. 8.

Los ejemplares de **A. wyvillei** obtenidos en 1969 oscilaban en tamaño entre 5 mm a 24 mm de diámetro. En estas colecciones no aparecían ejemplares grandes, ya que como existe una estratificación ontogénica, los individuos de mayor tamaño ocuparán lechos más profundos, mientras que los individuos


DISTRIBUCION BATIMETRICA
(BATHYMETRIC DISTRIBUTION)
FEBRERO – MARZO 1969
(FEBRUARY – MARCH 1969)
Atolla wyvillei
Atorella vanhoeffeni
Periphylla periphylla
DIA (DAY)
NOCHE (NIGHT)
PROFUNDIDAD m. (DEPTH m)
70110
90
75
60
9090
45
12090
70
55
0
200
400
600
110°
120°
20°
30°
40°


DISTRIBUCION BATIMETRICA
(BATHYMETRIC DISTRIBUTION)
MAYO-JUNIO 1969
(MAY-JUNE 1969)
Atolla wyvillei
Atorella vanhoeffeni
Periphylla periphylla
40°
30°
20°
110°
120°
70.110
90.75
60
60.45
90.90
55.45
70.
120.90
DIA (DAY)
NOCHE (NIGHT)
PROFUNDIDAD m. (DEPTH m.)
70.110
90
75
60
90.90
60
45
120.90
70
55
45
0
200
400
600


DIA (DAY)
NOCHE (NIGHT)
70.110
.90
.75
.60
90.90
.45
120.90
.70
.55
0
200
400
600
PROFUNDIDAD m. (DEPTH m.)
DISTRIBUCION BATIMETRICA
(BATHYMETRIC DISTRIBUTION)
AGOSTO-SEPTIEMBRE 1969
(AUGUST-SEPTEMBER 1969)
Atolla wyvillei
Atorella vanhoeffeni
Periphylla periphylla
40°
30°
20°
120°
110°



DISTRIBUCION BATIMETRICA
(BATHYMETRIC DISTRIBUTION)
NOVIEMBRE-DICIEMBRE 1969
(NOVEMBER-DECEMBER 1969)

pequeños ocupan estratos más someros, y estos ejemplares son los que aparecen en las colecciones. Durante mis estudios en aguas de California he logrado obtener representantes de **A. wyvillei** que alcanzaban 150 mm de diámetro, capturados en pescas con red mesopelágica, realizadas a más de 1000 m de profundidad.

Atorella vanhoeffeni ha sido observada previamente en regiones próximas a California, así Bigelow (1909) la cita para la región de Panamá, y Alvariño (1972) para la zona que se extiende desde Costa Rica al Golfo de Tehuantepec.

A. vanhoeffeni aparecía en las colecciones de 1969, con mayor frecuencia en las pescas nocturnas que en las diurnas, y solamente se observó en mayo, agosto, septiembre, noviembre y diciembre, es decir que no aparecía en las colecciones de invierno debido posiblemente a que las pescas no alcanzaron los niveles habitados por esta especie. **A. vanhoeffeni** se observó en mayo en la zona de Monterrey y San Diego, y solamente en las pescas nocturnas. En la zona de Monterrey ocupaba respectivamente los estratos de 350-225 m y 350-100 metros en las Estaciones 70.90 y 70.75 durante la noche, y en los 600-350 m de profundidad y 600-475, 350-225 m de profundidad en las Estaciones frente a San Diego (90.90, 90.45). Fig. 6.

Durante el verano, **A. vanhoeffeni** se extendía frente a Monterrey a 350-225 m y 600-475 m de día en las Estaciones 70.75 y 70.60, y a los 350-100 m de profundidad en la Estación 70.75 durante la noche. Frente a San Diego aparecía desde los 600-475 m durante el día en la Estación 90.45, y de noche en la misma Estación desde los 350-100 m de profundidad. En la región de Punta Eugenia se encontró solamente de día a 600.475 m de profundidad en la Estación 120.70. Fig. 7.

En el otoño se observó **A. vanhoeffeni** frente a Monterrey a los 600-475 m y 475-350 m durante el día en las localidades 70.75 y 70.60, y a los 600-475 m de profundidad durante la noche en la Estación 70.60. Frente a San Diego aparecía desde los 475-225 m en la Estaicón 90.60 durante el día, y de noche a los 475-350, 225-100 y 600-475, 350-225 en las localidades 90.90 y 90.60. Frente a Punta Eugenia aparecía desde los 600-350 m y a los 600-475 m de profundidad respectivamente en las localidades 120.90 y 120.50 durante el día, mientras que de noche se observó a 350-100 en la Estación 120.90. Fig. 8.

Los ejemplares de **A. vanhoeffeni** obtenidos durante los cruceros de 1969 alcanzaban unos 7 mm de ancho y de 3 a 5 mm de altura.

Periphylla periphylla es una Medusa batial que ostenta una amplia distribución oceánica avanzando en todos los océanos excepto en el Artico. La información que aparece publicada sobre la distribución batimétrica de esta especie está basada en los datos obtenidos durante varias expediciones científicas, y así Broch (1913), Kramp (1913, 1924, 1947, 1968), Stiasny (1934), Bigelow (1938) indican que se extiende desde los 1500 a los 400 m de profundidad, aunque en algunas regiones avanza hasta niveles más profundos y más someros. La máxima profundidad a que se ha encontrado parece estar en las inmediaciones de los 2700 metros de profundidad. Pérèes (1957) ha observado ejemplares de **P. periphylla** en el Mediterráneo entre 1300 y 1000 m de profundidad, indicando que las poblaciones se extienden siempre a lo largo de los estratos de unos 200 metros del fondo, pero evitando sin embargo la proximidad del fondo del océano.

Existe también una tendencia a que los individuos de mayor tamaño aparezcan a mayores profundidades, por lo tanto, las poblaciones de **P. periphylla** presentan una estratificación ontogénica, como sucede con otras, especies de Medusas y demás organismos del plancton. También, los ejemplares de **P. periphylla** que habitan lechos más profundos en el océano presentan un color rojo más oscuro, que llega al granate con tonalidades de un marrón oscuro.

P. periphylla se encontró en el Pacífico trópico oriental y en el Mar de Cortés (Bigelow 1940), y en el Golfo de Nicoya, Costa Rica, y aguas Guatemaltecas (Alvariño, 1972). En la región de California ha sido previamente observada (Alvariño, 1967) bajo la sinonimia de **P. hyacinthina** Steenstrup 1837, a 2000-1800, 850-700 y 300-250 metros de profundidad frente a San Diego en una zona de surgencia de aguas profundas. También ha sido observada (Alvariño, 1969) en el Mar de Cortés (bajo la sinonimia de **P. hyacinthina**).

P. periphylla ha sido observada en las colecciones mensuales realizadas durante el programa CalCOFI en aguas de California (Alvariño, 197) en pescas desde unos 140 m de profundidad hasta la superficie. Así aparece en mayo de 1954 en la Estación 100.35, en enero de 1958 en la Estación 70.80, en febrero de 1958 en la Estación 107.40, en abril de 1958 en la Estación 70.60, 100.90 y 100.65, en junio de 1958 en las Estaciones 63.70 y 90.80, y en enero de 1961 en las Estaciones 60.100 y 70.60. La presencia de **P. periphylla** en estratos poco profundos indica que en tales localidades ocurrían procesos de afloramiento de aguas profundas.

En las colecciones correspondientes a 1969, **P. periphylla** aparecía solamente en la primavera, verano y otoño, siendo más abundante y frecuente de noche que de día. Así en la primavera de 1969 aparecía a 350-225 m de profundidad Estaciones 70.90 y 70.75 y a 350-225 y 100-75 en la Estación 70.60 correspondientes en la zona de Monterrey, sin aparecer en las zonas de San Diego ni Punta Eugenia. En el verano se presentó de día frente a Monterrey a 475-350 m en la Estación 70.90, y de noche a los 475-350 m y 225-100 m, y frente a San Diego aparecía solamente de noche a los 350-225 m en la Estación más próxima a la costa, 90.45; mientras que en la zona de Punta Eugenia se encontró de noche a 350-225 m en la Estación 120.55 y a 600-475 m en la Estación 120.45.

En el otoño aparecía **P. periphylla** solamente en las Estaciones más nórdicas, así frente a Monterrey se observó a los 475-350 m y 600-475 m de profundidad respectivamente en las Estaciones 70.75 y 70.60, y a los 225-100 m de noche en la Estación 70.60.

El tamaño de los individuos de **P. periphylla** colectados oscilaba entre 100 mm a 14 mm de altura observándose una cierta estratificación de tallas, de modo que los ejemplares pequeños aparecían en estratos menos profundos que los ejemplares de mayor tamaño.

En otras colecciones que he analizado, procedentes de cruceros en aguas de California obtenidos en pescas con redes mesopelágicas, he observado

Tabla I. Distribucion batimetrica de *Aenina citrea* en la region de California, durante 1969

Crucero	Estacion	Profundidad m.	Hora y Fecha	PESCAS de DIA Numero de ejemplares Red babor	 red estribor	Total	Hora y Fecha	PESCAS de NOCHE Numero de ejemplares Red babor	 red estribor	Tota
6905	70.110	600-475					0140 18-V-69	15	0	15
		475-350						5	0	5
	70.90	600-475	1436 19-V-69				0053 20-V-69	0	5	5
		475-350		15	45	60		50	25	75
	70.75	600-475	1245 21-V-69				2353 20-V-69	40	45	85
		350-225						20	30	50
	70.60	350-225	1318 22-V-69				0020 22-V-69	0	5	5
	90.90	600-475					0244 28-V-69	0	5	5
		475-350						0	15	15
	90.60	600-475	1256 28-V-69	5	5	10	0032 28-V-69	–	10	20
	90.45	475-350					0115 29-V-69	5	0	5
		350-225						0	5	5
6906	120.55	475-350	1210 22-VI-69	0	10	10	2300 22-VI-69	15	0	15
6908	70.110	485-350	1000 19-viii-69	15	30	45	2130 19-VIII-69	35	15	50
		350-225						10	0	10
		225-100						20	10	30
	70.90	475-350	0930 17-VIII-69	10	0	10	2125 17-VIII-69	25	20	45
		350-225		20	10	30		15	0	15
	70.75	475-350	1030 16-VIII-69				2140 16-VIII-69	0	20	20
		350-225		0	35	35		0	5	5
	70.60	475-350	1000 15-VIII-69	0	5	5				
		350-225		5	5	10				
		225-100		0	5	5				

6909	90.90	600-475	0930 6-IX-69	0	20	20	2120 6-IX-69			
		475-350		5	5	10		10	10	20
	90.60	600-475	0930 5-IX-69				2130 4-IX-69	25	—	50
		475-350		30	5	35		10	0	10
	90.45	600-475	1010 3-IX-69				2200 3-IX-69	—	5	10
		475-359		5	0	5		0	5	5
		350-225		5	10	5				
		225-100						0	5	5
	120.90	475-350	0915				2130 28-IX-69	5	0	5
	120.70	600-475	0915 28-IX-69				2116 27-IX-69	0	5	5
	120.55	600-475	0932 27-IX-69	5	0	5				
6911	70.75	600-475	0930 21-XI-69	5	20	25				
		475-350		10	5	15				
	70.60	600-475	1258 20-XI-69	—	50	100				
		475-350		10	—	20	2135 20-XI-69	0	20	20
		350-225		5	10	15				
6912	90.90	475-350	1145 14-XII-69	0	5	5				
	90.60	600-475	1235				2355 12-XII-69	0	15	15
		475-350		0	20	20		0	10	10
		350-225		10	0	10				
	90.45	475-350					0010 3-XII-69	5	—	10
	120.90	475-350	1200 10-XII-69				2325 9-XII-69	0	5	5
		350-225						0	5	5

Tabla 3 . Distribucion batimetrica de Colobonema sericeum en la region de California, durante 1969

Crucero	Estacion	Profundidad m.	Hora y Fecha	PESCAS de DIA Numero de ejemplares Red babor	 red estribor	Total	Hora y Fecha	PESCAS de NOCHE Numero de ejemplares Red baber	 red estribor	Tota
6905	70.110	600-475	1343 17-V-69	5	0	5				
	70.90	475-350		0	5	5				
		350-225					0053 20-V-69	10	5	15
	70.75	600-475	1245 21-V-69				2353 20-V-69	0	5	5
		475-350		—	15	30				
		350-225		25	0	25				
	70.60	350-225	1318 22-V-69				0020 22-V-69	5	10	15
	90.90	475-350					0244 28-V-69	0	10	10
	90.60	350-225	1256 28-V-69				0032 28-V-69	0	5	5
	90.45	475-350					0115 29-V-69	25	25	50
		350-225						0	5	5
6906	120.70	600-475	1230 21-VI-69	0	5	5				
		475-350		0	5	5				
6908	70.110	475-350	1000 19-VIII-69	0	5	5				
	70.90	475-350	0930 18-VIII-69				2125 17-VIII-69	10	0	10
		350-225		10	0	10		0	5	5
		225-100						—	5	10
	70.75	475-350	0930 18-VIII-69				2125 17-VIII-69	0	5	5

6909	90.90	475-350	0930 6-IX-69	0	5	5				
	90.60	600-475	0930 5-IX-69	—	10	20	2130 4-IX-69	5	—	10
		475-350		5	0	5				
		350-225		10	5	15				
	90.45	600-475	1010 3-IX-69	—	5	10				
		475-350					2200 3-IX-69	5	0	5
	120.90	600-475	0915 29-IX-69	5	0	5				
	120.45	600-475	0955 26-IX-69				2120 25-IX-69	5	0	5
		475-350		5	10	15				
		350-225						0	5	5
6911	70.75	475-350	0930 21-XI-69	0	5	5				
	70.60	600-475	1258 20-XI-69	—	5	10				
		475-350		5	—	10				
		225-100					2135 20-XI-69	5	5	10
6912	90.90	600-475	1145 14-XII-69	—	5	10				
		475-350		0	5	5				
	90.60	350-225		0	5	5				
	90.45	350-225		0	5	5				
	120.90	475-350	1200 10-XII-69	5	0	5	2325 9-XII-69	5	0	5
		350-225						5	5	10
	120.70	600-475					2325 8-XII-69	0	5	5
	120.45	350-225					2345 5-XII-69	0	10	10

Tabla 2 . Distribución batimetrica de *Aeginura grimaldii* en la region de California , durante 1969

Crucero	Estacion	Profundidad m.	Hora y Fecha	P E S C A S de DIA Numero de ejemplares			Hora y Fecha	P E S C A S de NOCHE Numero de ejemplares		
				Red babor.	red estribor	Total		Red babor	red estribor	Total
6902	70.75	75-50	1619 23-II-69	0	1	1				
6905	70.110	350-225	1343 17-V-69				0140 18-V-69	0	5	5
	70.90	475-350	1438 19-V-69	0	5	5				
6908	70.90	475-350	0930 18-VIII-69	5	10	15				
		225-100					2125 17-VII-69		10	20
		100-75	2115 18-VIII-69				0030 18-VIII-69	12	3	15
		75-50		2	0	2		91	2	93
		50-25						1	0	1
	70.75	475-350	1030 16-VIII-69				2140 16-VIII-69	0	20	20
		350-225		0	215	215				
		75-50					0300 17-VIII-69	2	1	3

Tabla 4. Distribucion batimetrica de *Halicreas minimum* en la region de California, durante 1969

Crucero	Estacion	Profundidad m.	Hora y Fecha	PESCAS de DIA Numero de ejemplares			Hora y Fecha	PESCAS de NOCHE Numero de ejemplares		
				Red babor.	red estribor	Total		Red babor	red estribor	Total
6905	70.60	475-350	1318 22-V-69	35	40	75	0020 22-V-69	20	20	40
6909	120.70	600-475	0915 28-IX-69	5	0	5				
	120.45	600-475					2120 25-IX-69	0	5	5
6911	70.75	475-350	0930 21-XI-69	25	20	45				
		350-225		0	10	10				
6912	120.70	600-475	1222 8-XII-69	5	0	5	2325 8-XII-69	0	5	5
	120.55	600-475	1220 7-XII-69	5	0	5				

Tabla 5 . Distribucion batimetrica de algunas especies de medusas en la region de California, durante 1969

Especies	Crucero	Estacion	Hora	Profundidad en metros	NUMERO DE EJEMPLARES		
					Red babor	Red estribor	Total
Pantachogon haeckeli	6912	90.60	noche	600-475	10	0	10
Chromatonema rubrum	6912	90.90	dia	475-350	5	0	5
Calycopsis simulans	6905	70.90	dia	475-350	10	0	10
		70.75	dia	350-225	5	0	5
Euphysora gigantea	6909	120.90	noche	600-475	1	0	1
Nausithoe punctata	6912	120.90	noche	600-475	0	5	5

Tabla 6. Distribucion batimetrica de Atolla wyvillei en la region de California, durante 1969

Crucero	Estacion	Profundidad m.	Hora y Fecha	PESCAS de DIA Numero de ejemplares Red babor	 red estribor	 Total	Hora y Fecha	PESCAS de NOCHE Numero de ejemplares Red babor	 red estribor	 Total
6903	90.60	335-225	1439 10-III-69				0053 2-III-69	0	5	5
		100-75	1348 10-III-69					0	5	5
	120.70	200-150					0318 7-III-69	0	5	5
6905	70.90	600-475	1438 19-V-69				0053 20-V-69	5	10	15
	70.75	600-475	1245 21-V-69	0	5	5				
		350-225					2353 20-V-69	20	0	20
	70.60	600-475	1318 22-V-69	30	75	105				
		350-225					0020 22-V-69	0	20	20
		225-100						15	10	25
	90.60	350-225	1256 26-V-69				0032 28-V-69	0	5	5
6908	70.90	475-350	0930 18-VIII-69	0	5	5				
6909	90.45	600-475	1010 3-IX-69				2200 3-IX-69	—	5	10
		475-350		0	15	15				
6912	90.90	600-475	1145 14-XII-69	—	5	10	2255 14-XII-69	—	5	10
		225-100						0	5	5
	120.45	350-225	1230 6-XII-69				2345 5-XII-69	5	10	15

Table 7. Distribucion batimetrica de Atorella vanhoeffeni en la region de California, durante 1969

Crucero	Estacion	Profundidad m.	Hora y Fecha	P E S C A S de DIA Numero de ejemplares			Hora y Fecha	P E S C A S de NOCHE Numero de ejemplares		
				Red babor	red estribor	Total		Red babor	red estribor	Total
6905	70.90	350-225	1438 19-V-69				0053 20-V-69	5	5	10
	70.75	350-225	1245 21-V-69				2353 20-V-69	0	15	15
		225-100						5	5	10
	90.90	600-475					0244 28-V-69	10	10	20
		475-350						10	10	20
	90.45	600-475					0115 29-V-69	0	10	10
		350-225						0	15	15
6908	70.75	350-225	1030 18-VIII-69	0	5	5	2140 16-VIII-60	10	0	10
		225-100						0	5	5
		100-75					0300 17-VIII-69	—	5	10
	70.60	600-475	1000 15-VII-69	—	5	10				
6909	90.45	600-475	1010 3-IX-69	—	20	40				
		350-225					2200 3-IX-69	20	15	35
		225-100						0	5	5
	120.70	600-475	0915 28-IX-69	5	0	5				
6911	70.75	600-475	0939 21-XI-69	0	5	5				
	70.60	600-475					2135 20-XI-69	0	5	5
		475-350		5	—	10				
6912	90.90	475-350	11 45 14-XII-69				2255 14-XII-69	10	5	15
		225-100						5	5	10
	90.60	600-475	1235 13-XII-69				2355 12-XII-69	10	5	15
		475-350		0	15	15				
		350-225		0	15	15		0	5	5
	120.90	600-475	1200 10-XII-69	0	5	5				
		475-350		10	0	10				
		350-225					2325 9-XII-69	0	5	5
		225-100						5	0	5
	120.55	600-475	1220 7-XII-69	0	5	5				

Tabla 8. Distribucion batimetrica de *Periphylla periphylla* en la region de California, durante 1969

Crucero	Estacion	Profundidad m.	Hora y Fecha	PESCAS de DIA Numero de ejemplares			Hora y Fecha	PESCAS de NOCHE Numero de ejemplares		
				Red babor	red estribor	Total		Red babor	red estribor	Total
6905	70.90	350-225	1438 19-V-69				0053 20-V-69	0	5	5
	70.75	350-225	1245 21-V-69				2353 20-V-69	0	5	5
	70.60	350-225	1318 22-V-69				0020 22-V-69	0	20	20
		100-75	1006 22-V-69				2220 21-V-69	0	5	5
6908	70.90	475-359	0930 18-VIII-69	0	5	5	2125 17-VIII-69	0	5	5
		225-100						—	5	10
6909	90.45	350-225	1010 3-IX-69				2200 3-IX-69	5	10	15
	120.55	350-225	0932 27-IX-69				2115 26-IX-69	0	5	5
	120.45	600-475	0955 26-IX-69				2120 25-IX-69	5	5	10
6911	70.75	475-350	0939 21-XI-69	5	0	5				
	70.60	600-475	1258 20-XI-69	—	5	10				
		225-100					2135 20-XI-69	5	5	10

ejemplares de **P. perihpylla** de unos 160 mm de altura, procedentes de zonas a más de 1000 m de profundidad. Figs. 6, 7, 8.

Nausithoë punctata aparece en las colecciones aquí estudiadas representada por cinco ejemplares obtenidos en las muestras de diciembre de 1969 correspondientes a la Estación 120.90, frente a Punta Eugenia, a profundidades de 600.475 m en pescas nocturnas.

La distribución que presentan las especies de día y de noche no indica en todos los casos que se produce una migración batimétrica de las poblaciones regulada por la luz, lo cual nos sugiere que hay otros factores, además de la luz que afectan a la distribución vertical de las poblaciones planctónicas.

Es de interés hacer resaltar la importancia que tiene conocer con detalle la distribución tridimensional de las Medusas, no solamente porque indican particularidades en las condiciones de la dinámica oceánica, sino que estos organismos son depredadores muy activos en las comunidades oceánicas, devorando huevos, larvas y animales jóvenes correspondientes a diversas especies de peces y otros zoplanctontes de importancia en la economía del mar.

Las Medusas batiales se alimentan de los organismos que habitan los mismos estratos batiales, como son los peces Myctófidos. Estos peces aun cuando no se utilizan para el consumo humano, ni tienen valor en la pesca comercial, son muy abundantes y constituyen la dieta básica de otros animales marinos, de ahí que un consumo extraordinariamente excesivo de los Myctófidos producido por las Medusas ocasionaría un grave desequilibrio en la dieta de otros peces, que son de gran valor comercial, ya que los Myctófidos sirven de alimento a las diversas especies de Escombrideos y Xifideos, formando parte además de la dieta de delfines y Cetáceos.

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7503

Influence of interannual climatic fluctuations on biological systems

Growth of conifers in western North America and the distribution of albacore tuna (*Thunnus alalunga*) along the west coast of North America are linked by large scale atmospheric flow patterns which are influenced by air–sea interaction processes over the eastern North Pacific. Although the systems respond to their respective environments during different times of the year there is strong evidence that they are reacting to the same climatic fluctuations.

Ring widths of conifers from a variety of semi-arid sites in western North America reflect climatic variations. The spatial anomaly patterns of tree growth have been related to large scale anomaly patterns of the general atmospheric circulation which, in turn, are related to anomaly patterns of sea-surface temperature (see, for example, refs 1 and 2).

Seasonal migrations of albacore tuna into and out of the coastal North American fishery and the population distribution along the coast are related to changes in the thermal structure of the eastern North Pacific which, in turn, are related to air–sea interaction events[3].

Although it would be desirable to know the yearly variations in the distribution of albacore abundance or the exact number of individuals in the population, the best source of available data is landing statistics compiled for various regions along the North American coast (J. A. Renner, personal communication). These data indicate albacore availability, or accessibility to the efforts of a fishery. A complex situation probably exists where fluctuations in landings result both from environmental influences affecting albacore migration routes (causing yearly variations in their geographical distribution along the coast) and from weather conditions affecting the location and success of the fishermen and/or the behaviour of the fish once they are distributed.

As an indicator of variations in albacore population distribution, the landings reported north of San Francisco were expressed as a percentage of those reported along the entire coast. This assumes the fishing effort is spread along the entire coast throughout each fishing season. Although a complete effort analysis has not been made, boats were operating consistently along the entire coast throughout the analysis period.

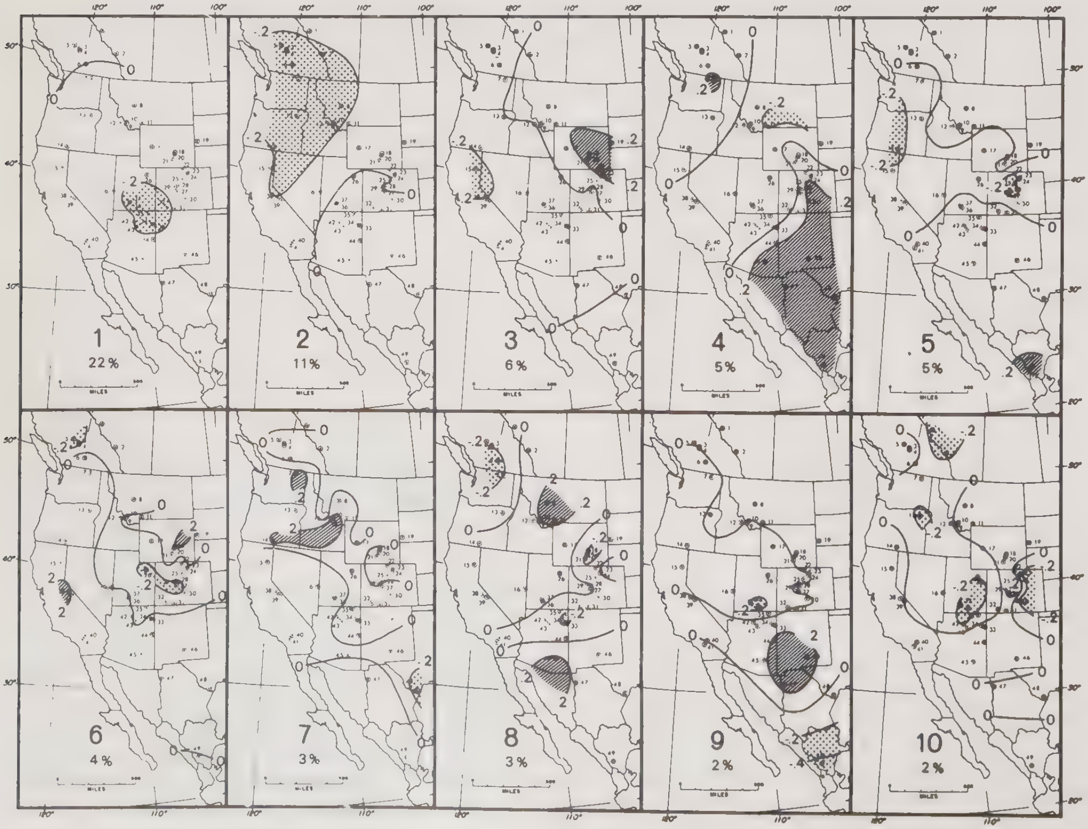
To determine whether spatial patterns of tree growth from 49 sites in western North America and albacore distribution both respond to the same variations in the ocean–atmosphere system, the large scale components of the ring-width variance were transformed into uncorrelated variables (amplitudes of principal component eigenvectors) and then put in stepwise regression to find which of these amplitudes were significant predictors (at the 95% confidence level) of albacore catch. This procedure gave the equation:

$$Y=35.12+5.76A_2+5.13A_8+8.56A'_4-6.17A'_9+11.54A'_{10} \quad (1)$$

where Y is the estimated percentage of albacore caught north of San Francisco, A and A' are eigenvector amplitudes corresponding to the catch year and the following year, respectively, and subscripts refer to the eigenvector number (Fig. 1). The regression accounted for 83% of the catch data variance in the calibration period (Fig. 2). The values of tree-growth eigenvector amplitudes for 1700 to 1938 were then substituted into equation (1) to estimate what the yearly albacore catch distribution would have been for this early period based on the patterns of tree growth (Fig. 3).

Although fishery statistics are available after 1961, tree-growth data for all 49 sites within the spatial network are not, and the only independent data available to check the validity of the reconstruction are incomplete fishery catch statistics between 1904 and 1937 (ref. 4). A qualitative comparison between both sets of data shows these common

Fig. 1 Maps of the first 10 eigenvectors of ring-width index. The percentage figures refer to the variance accounted for by the corresponding eigenvector. Numbered circles indicate ring-width chronology sites.



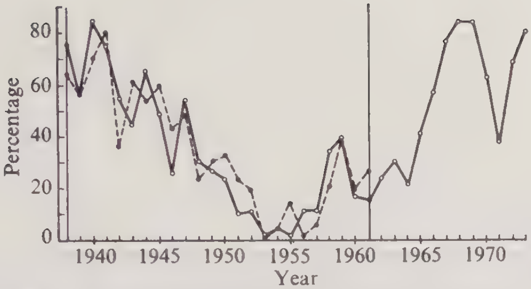


Fig. 2 Percentage of the total North American west coast albacore tuna catch taken north of San Francisco, estimated from landings data (———) and percentage catch taken north of San Francisco derived from the calibration equation applied to tree-growth data over the dependent data period (- - - - - -). Calibration included the following steps: (1) We computed the 49 by 49 correlation matrix which expressed the interrelationships among the 49 ring-width index series for the period of analysis (1700–1962). (2) The eigenvectors of the correlation matrix were then computed. These (orthogonal) eigenvectors may be expressed in map form as characteristic spatial anomaly patterns of tree growth. The 10 eigenvector patterns which accounted for the most variance (the large scale variance) were selected for further analysis. Maps of these eigenvectors are shown in Fig. 1. Linear combinations of these 10 eigenvectors can reproduce 64% of the ring-width variance for the 49 chronologies during the period of analysis. (3) Each of the first 10 eigenvectors was multiplied by the normalised tree-growth data at each site for each year from 1700 to 1962. The resulting matrix product consists of 10 time series of amplitudes which give the relative importance of each of the first 10 eigenvector patterns (the large scale patterns) in each year's tree-growth anomaly map. Being orthogonal to (uncorrelated with) each other they are easy to use as predictor variables in multiple regression. (4) Since trees respond to the climate of both the concurrent season and previous seasons, a prediction model was constructed including the 10 amplitudes corresponding to the same year as the catch data and the 10 amplitudes corresponding to the year following the catch data, for a total of 20 possible predictor variables. (5) Stepwise multiple regression was used to find those amplitudes that were significant predictors (95% confidence level) of albacore catch distribution for the years 1938–61.

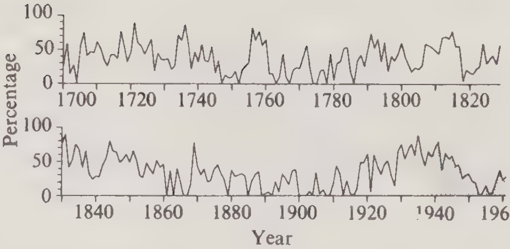


Fig. 3 Percentage of the total albacore tuna catch taken north of San Francisco, estimated from the calibration equation applied to tree-growth data for 1700 to 1961. Shading indicates calibration period.

characteristics: a fishery that was centred off southern California in the early 1900s; a sharp decrease in the availability of albacore to the southern fishery between 1917 and 1918; another decrease in availability of albacore to the southern fishery in 1923 when the total catch was the lowest since 1918; and a prolonged period of decreased availability to the southern fishing fleet after 1928. The reconstructed distribution data indicate that a fishery would have been centred quite far north after 1929 and through the late 1930s if boats had operated there during that period. The absence of albacore from the catch record for Oregon and Washington before 1937 and low catches for California after 1925 probably reflect the extreme northward and offshore population distribution indicated by the reconstructed data; the fish were just not available to salmon trollers that did operate close to shore north of California during this period[5].

We also examined the eigenvector patterns of tree growth that were chosen by regression to be associated with a high percentage of albacore caught north of San Francisco. The tree-growth pattern corresponding to the year of the catch

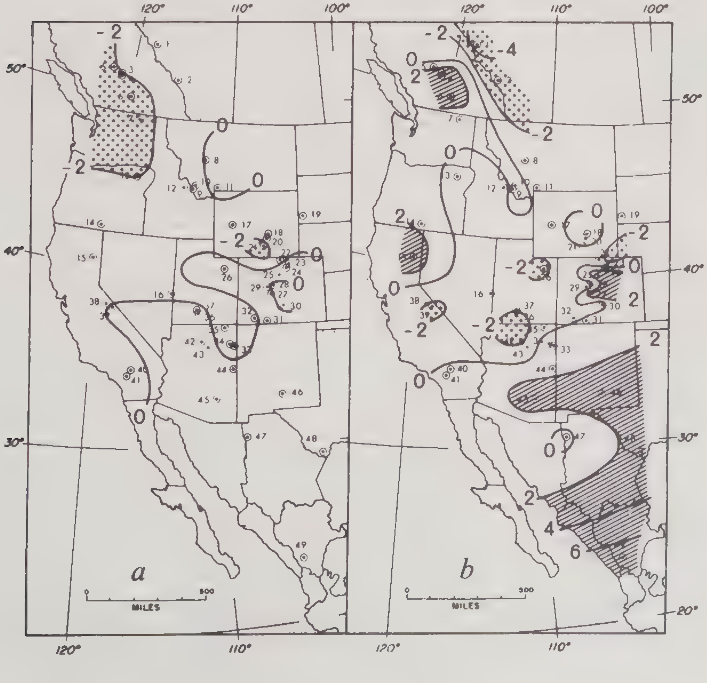


Fig. 4 Tree-growth anomaly patterns associated with above normal percentages of albacore caught north of San Francisco. Map *a*, corresponding to the year of the catch, is formed from the linear combination of eigenvectors 2 and 8 in equation (2); map *b*, corresponding to the year following the catch, is formed from the linear combination of eigenvectors 4, 9, and 10 in equation (3).

can be represented by a map composed of eigenvectors 2 and 8 as follows:

$$\text{map } a = 5.76\,(\text{eigenvector } 2) + 5.13\,(\text{eigenvector } 8) \qquad (2)$$

where the numerical coefficients are taken from equation (1). Similarly, the tree-growth anomaly pattern corresponding to the year following a high percentage of albacore caught north of San Francisco can be represented as:

$$\text{map } b = 8.56\,(\text{eigenvector } 4) - 6.17\,(\text{eigenvector } 9) + 11.54 \text{ eigenvector } 10) \qquad (3)$$

These maps are presented in Fig. 4. The ring-width data were mostly from trees sited in arid localities, so that a wide ring would generally be associated with anomalously cool, cloudy weather and above normal precipitation whereas a narrow ring would reflect warm, sunny and dry conditions.

Below normal tree growth in the Pacific North-west (Fig. 4) is indicative of dry conditions associated with below normal cyclonic activity during the fishing season. Sunny and mild weather would favour albacore fishing in adjacent waters, as would above normal insolation regardless of weather. The resulting excess of stored heat in the ocean would be given up through evaporation during the following autumn and winter and lead to increased cyclonic activity and precipitation along the coast north of San Francisco. These conditions would lead to increased tree growth during the following growing season (Fig. 4).

Autumn and winter climatic anomaly features, combined with spring climate and the year-to-year autocorrelation of tree-ring widths, produce the other ring-width anomaly features in Fig. 4 for the following growing season. Narrow ring widths south of San Francisco, for example, imply below normal precipitation—an expected feature since winter precipitation in the Pacific North-west is negatively correlated with winter precipitation in southern California[6].

The reconstructed values of albacore catch distribution data (Fig. 3) and inferred population distribution also seem to exhibit long term changes over intervals of 100 yr or more, which suggest the possibility that long term fluctuations in the ocean–atmosphere system may be involved.

The success of the calibration of tree rings with albacore catch indicates the possibility of relating tree-ring variations to any type of biological variations which are affected by large scale climatic fluctuations. Such relationships may be quantified and used to reconstruct objectively other climatically-caused biotic variations in the past.

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Mariners Weather Log

RADIO FACSIMILE INFORMATION TO THE TROPICAL PACIFIC TUNA FLEET

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Tuna fishermen on the high-seas fishing grounds in the eastern tropical Pacific are wary of the tropical cyclones, the chubascos, and the severe local wind conditions, such as tehuantepecers, which typically occur in the area. Accurate information on the location and intensity of these storms was not always available to the fisherman when needed. In 1970, a program was developed at the National Marine Fisheries Service (NMFS), Southwest Fisheries Center (SWFC), La Jolla, Calif., to provide the tuna fleet with information on weather and fishing conditions on a regular basis, in exchange for environmental data from the fishing grounds. Such data are needed by NMFS scientists for studying the effects of environmental fluctuations on the distribution and availability of tropical tunas, and for developing fishery-forecasting techniques applicable to the management and harvesting of fishery resources. The data are also needed for preparing the fishery advisories; consequently, it is essential that fishermen report their observations in a timely manner.

One obstacle to the recruitment of tuna vessel captains into a real-time environmental observation program was a reluctance to reveal their position to competitors. This obstacle was removed by use of an encoding scheme for transmitting data messages. The Navy's Fleet Numerical Weather Central (FNWC), Monterey, Calif., cooperated in implementing the scheme, whereby each participating vessel is furnished with its own unique encoding chart. The decoding keys are stored in the FNWC computer, which processes the coded messages, feeds the data to the Navy's analysis and predictions programs, and routes the decoded observations back to the SWFC and also to the National Weather Service (NWS) Forecast Office, Redwood City, Calif.

Participating tuna vessels, which numbered more than 70 at the start of the 1975 fishing season, are expected to make and transmit marine surface weather observations once each day while on the fishing grounds. These include windspeed and direction, air temperature, sea-surface temperature, barometric pressure, weather, cloud cover, swell direction, and wave height. In addition, some 25 vessels are equipped with bathythermograph (XBT) systems with which subsurface temperatures can be measured and recorded. FNWC furnishes some of the XBT systems and the expendable probes through the SWFC to these vessels in exchange for data transmitted in the BATHY message format, which gives temperatures and depths down to 500 m.

In practice, tuna vessels at sea begin transmission of weather and BATHY messages about midafternoon each day, to NMFS-licensed radio station WWD, operated by the Scripps Institution of Oceanography and located at La Jolla, Calif. The messages are relayed via a data line through SWFC to the computer at FNWC, decoded and processed, and sent back to SWFC and to NWS, Redwood City, for use in preparing the daily analyses of wind and sea conditions. The processed BATHY data are also returned to SWFC on punched cards and in reconstructed computer plots of temperature-depth profiles, for research use.

At the time the program was conceived, no tuna vessels carried the special equipment necessary for radio facsimile (FAX) reception. The SWFC procured approximately 60 facsimile recorders from Government surplus and adapted them for use with shipboard radio communications equipment. These recorders were installed on selected San Diego-based tuna boats on an experimental basis beginning in 1971. They proved so valuable that more than a dozen other boats have since purchased their own facsimile recorders in order to receive the advisories.

Station WWD transmits two FAX advisory charts daily, beginning about 2300. One of the charts gives average windspeeds and directions expected during the next 24 hr, the locations and expected movements of tropical cyclones, areas of squalls, and the configuration of the Intertropical Convergence Zone (ITCZ). Figure 1 shows the wind and weather advisory chart issued on July 16, 1974. The ITCZ was displaced north of its usual location at longitude 110°W (10° to 15°N in July), where tropical storm Francesca was approaching the tip of Baja California. Chubascos are shown near 10°N, 126°W, and 14°N, 117°W, while an incipient cyclonic circulation is indicated near 12°N, 95°W. Such disturbances can intensify suddenly; consequently, adequate forewarning can help boats avoid potentially hazardous situations.

Figure 2 shows the sea-state advisory chart for the same day. Swell directions are indicated by arrows, while predicted swell heights and wave heights are given by the plotted numbers. Sea and swell conditions are particularly important in purse seine operations because they affect deployment and retrieval of the net and safety of the crew.

In addition to the daily wind and weather and sea-state advisories, three charts depicting ocean temperatures are prepared and transmitted weekly by radio facsimile. These are a sea-surface temperature analysis (fig. 3), a mixed-layer depth analysis (fig. 4), and a sea-surface temperature difference analysis, which compares present conditions with those in the corresponding week of the previous year. These charts are prepared in order to provide to the fisherman environmental information which is deemed to be useful, and thereby enlist his cooperation in developing the potential application of such information to fishing strategy. For example, preliminary studies at the SWFC suggest that the highest frequency of successful sets on yellowfin tuna occurs with sea-surface temperatures of approximately 80° to 83°F (26.7° to 28.3°C). Knowing this, a tuna-boat captain can use the sea-surface temperature charts as an aid in determining where to fish. The mixed-layer depth charts might be used as an aid in judging the probable success of purse seine fishing operations. Shallow mixed-layer depths are believed to favor successful sets, particularly when the vertical temperature gradient just below the bottom of the mixed layer is strong, because the fish are less likely to escape the net if it requires that they swim down through the thermocline into cold water below. The temperature difference charts, along with a fisherman's past experience, can assist him in judging the significance to fishing success of changes in environmental conditions.

Much of the present knowledge of environmental-fishery relationships is qualitative and, to some extent, speculative. The research in progress at the SWFC, based on environmental observations and catch statistics from the fleet, is aimed at defining and quantifying these relationships to a degree that will benefit both the harvesting and management of tuna resources.

The FAX advisory charts are based on environmental observations and analyses from many sources, which include fishing vessels, merchant ships, weather satellites, the FNWC, the National Environmental Satellite Service (NESS), and the NWS. Nevertheless, the eastern tropical Pacific is affected by a chronic

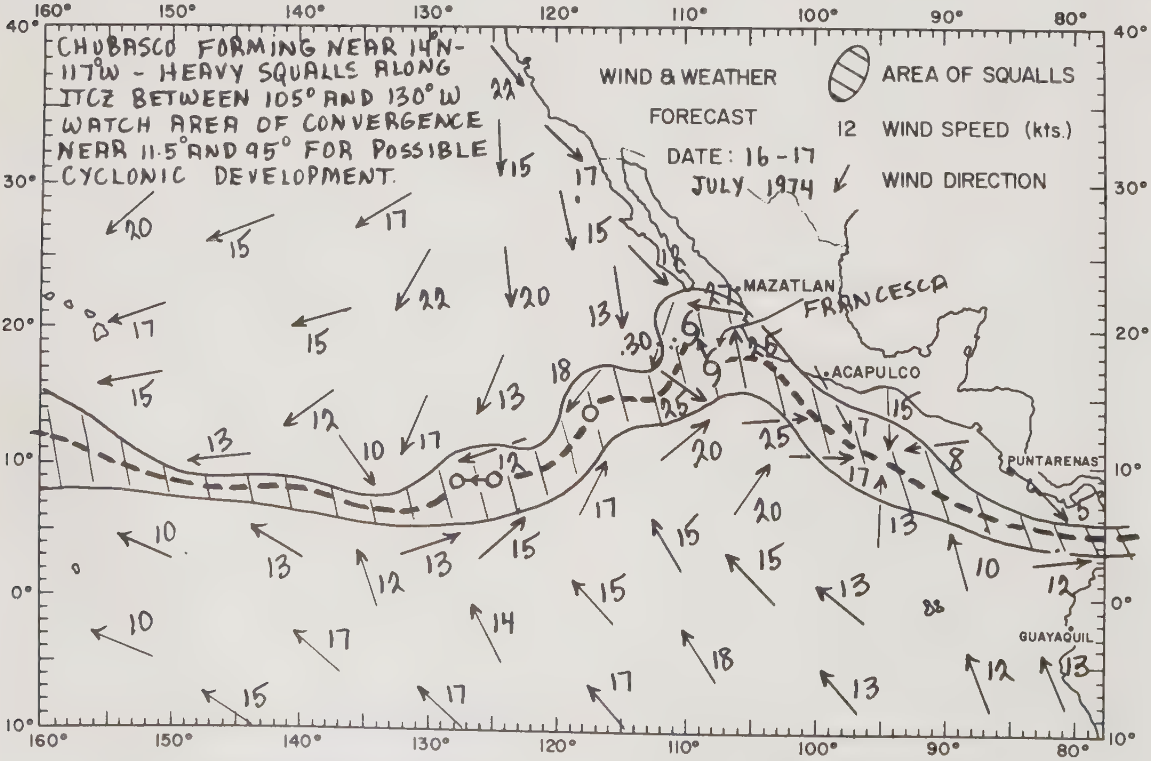

Figure 1.--Wind and weather advisory chart transmitted by radio facsimile on July 16, 1974.

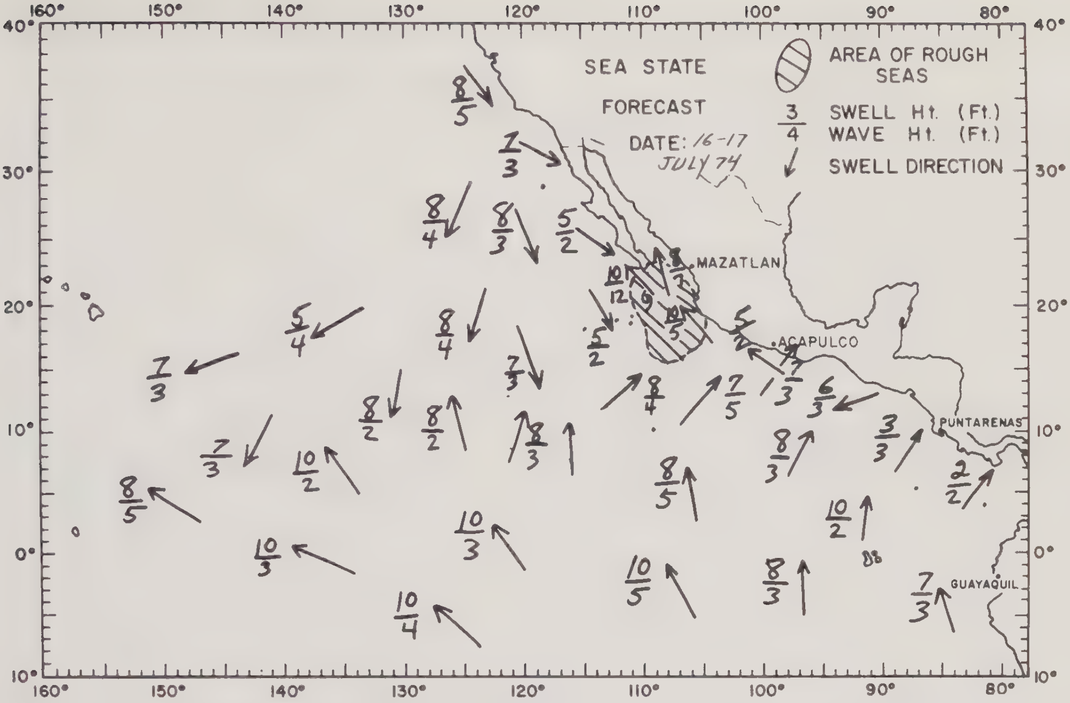
SEA STATE
FORECAST
DATE: 16-17 JULY 74
AREA OF ROUGH SEAS
3/4 SWELL Ht. (Ft.) WAVE Ht. (Ft.)
SWELL DIRECTION
MAZATLAN
ACAPULCO
PUNTARENAS
GUAYAQUIL
160° 150° 140° 130° 120° 110° 100° 90° 80°
40° 30° 20° 10° 0° 10°

Figure 2.--Sea-state advisory chart transmitted by radio facsimile on July 16, 1974.

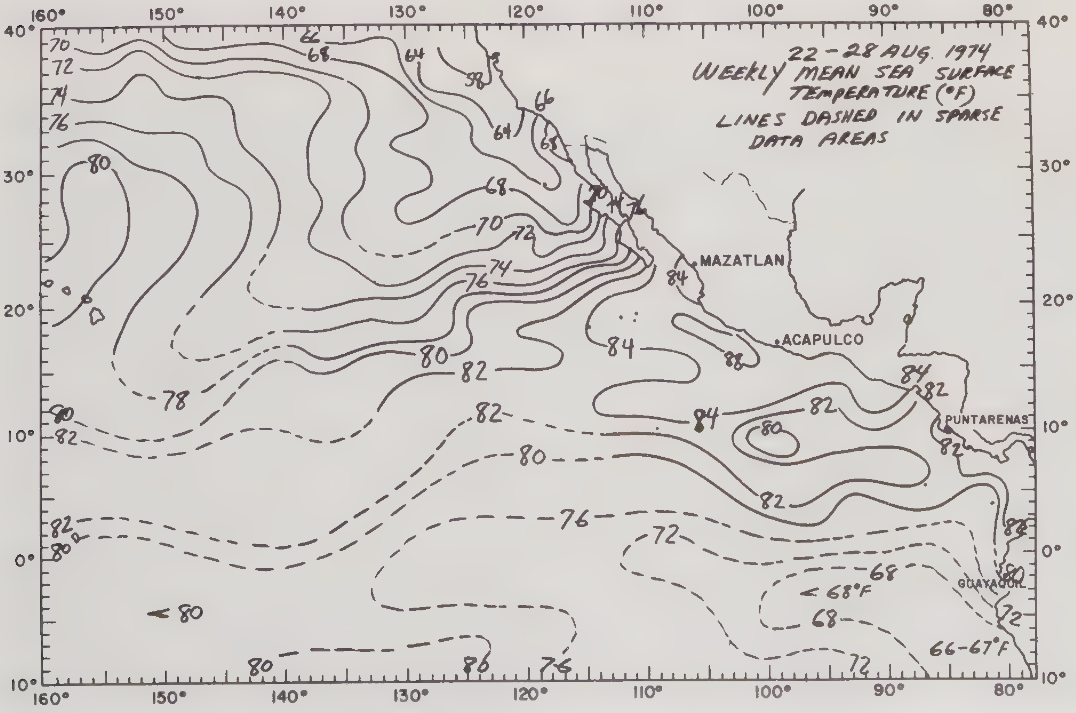
22-28 AUG. 1974
WEEKLY MEAN SEA SURFACE TEMPERATURE (°F)
LINES DASHED IN SPARSE DATA AREAS
MAZATLAN
ACAPULCO
PUNTARENAS
GUAYAQUIL
< 68°F
66-67°F
< 80
160° 150° 140° 130° 120° 110° 100° 90° 80°
40° 30° 20° 10° 0° 10°

Figure 3.--Weekly sea-surface temperature chart for the period August 22-28, 1974. This chart was transmitted by radio facsimile on August 29, 1974.

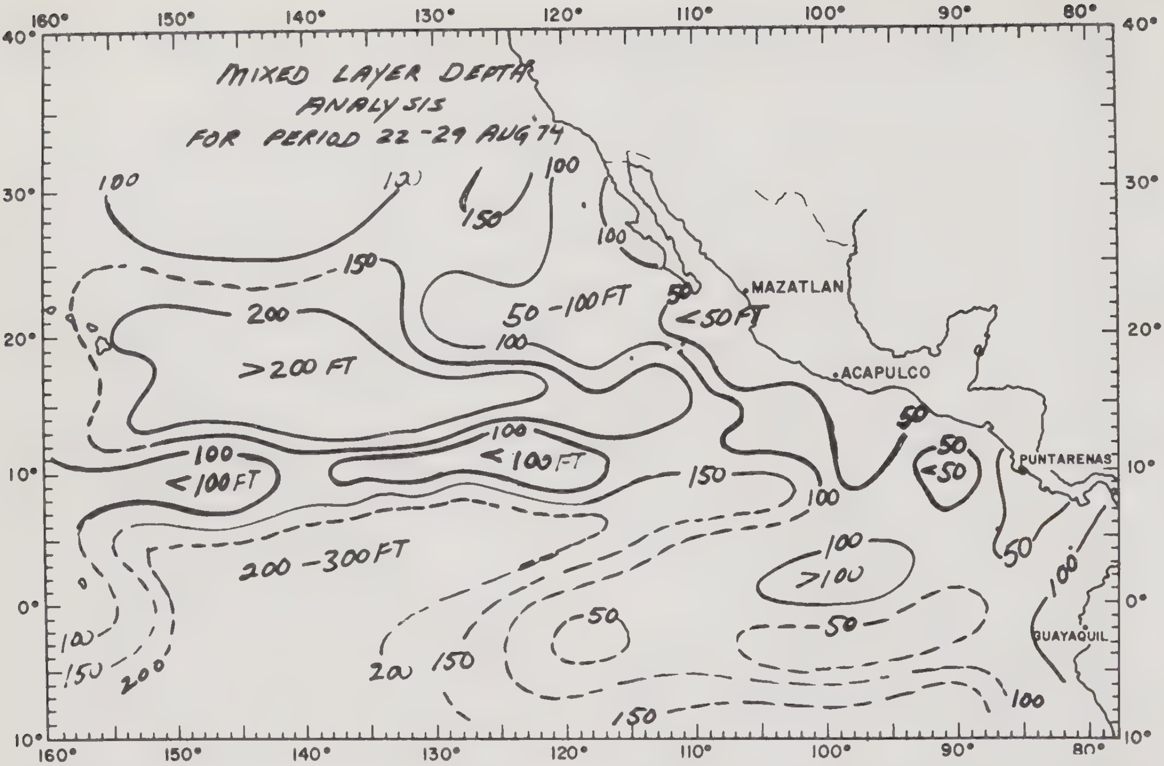

Figure 4.--Weekly mixed-layer depth chart for the period August 22-28, 1974. This chart was transmitted by radio facsimile on August 30, 1974.

deficiency of data and poses a difficult problem for marine analysts and forecasters. Consequently, in developing procedures for the preparation of wind, weather, and sea-state forecasts, emphasis was placed on the construction of a daily composite wind streamline analysis as the primary analysis tool. The streamline charts are not broadcast with the FAX charts, but enable the analyst to maintain careful day-to-day continuity, so that the course of tropical cyclone activity and other phenomena can be monitored with reasonable confidence, even when observations are sparse.

A reproduction of the streamline analysis for August 24, 1974, is shown in figure 5. The short arrows indicate observed wind directions and represent a sample of the observations reported by fishing vessels and merchant ships. The numbers plotted near the heads of the arrows give windspeed in knots. Three hurricanes (Ione, Kirsten, and Joyce) were active on this day, along with one tropical storm (Lorraine). The locations of these storms in the streamline analysis conform to those given for 1800 August 24, in the NWS San Francisco Eastern Pacific Hurricane Center Marine Advisories. The cyclonic circulation near 13°N, 101°W, detected off Costa Rica a few days earlier, became tropical storm Maggie on August 26.

The locations of the storm centers shown in figure 5 were all determined from weather satellite pictures. An excellent example is presented in figure 6, which shows hurricanes Ione (left) and Kirsten (right) at about 1750 on August 24. The picture was generated in the visible range with the very high resolution radiometer aboard the satellite NOAA-3 during a north-to-south overpass. A portion of the subpoint track (projection of the satellite's orbit onto the Earth's surface) is indicated by the dashed line in figure 5, which can be seen to pass nearly midway between the two hurricanes. On its preceding orbit, about 2 hr earlier, NOAA-3 passed over the area just east of Joyce and Lorraine, affording good fixes on those storms.

The availability of satellite imagery with comprehensive coverage of oceanic regions is obviously of tremendous value for monitoring conditions in the marine environment. Surface observations from fishing vessels and merchant ships are still essential, however, for determining surface wind, sea temperature, sea state, and other properties, and for providing "ground truth" to support continued development of remote-sensing technology.

Since August 1974, the daily wind and weather and sea-state advisory charts broadcast from station WWD have been prepared by the NWS San Francisco Weather Service Forecast Office (WSFO). The assumption by NWS of this service reflects a strengthening of the marine program at the San Francisco WSFO, which also prepares midlatitude analyses and prognoses for the North Pacific, for radio facsimile transmission from radio station NMC, San Francisco.[1] The NWS

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[1] Radio facsimile transmission schedules of weather and sea conditions, along with transmission frequencies, are contained in the U.S. Department of Commerce publication "Worldwide Marine Weather Broadcasts," issued jointly by the National Weather Service and the Naval Weather Service Command.

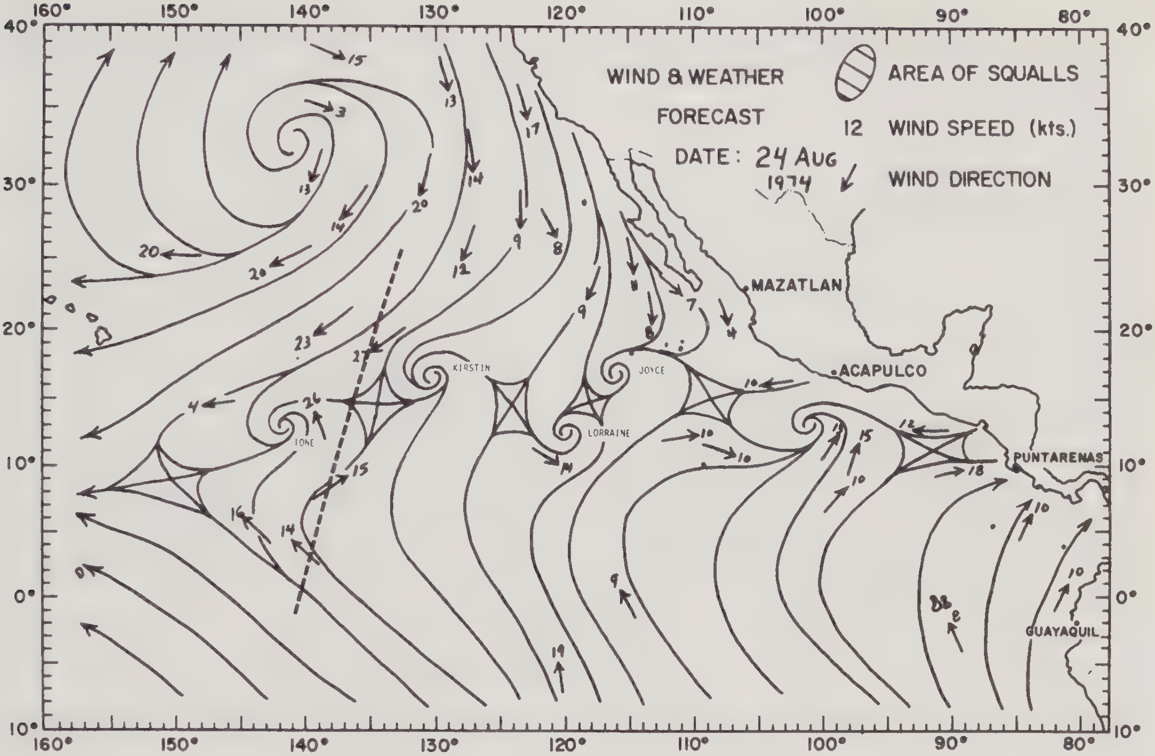
WIND & WEATHER
FORECAST
DATE: 24 AUG 1974
AREA OF SQUALLS
12 WIND SPEED (kts.)
WIND DIRECTION
MAZATLAN
ACAPULCO
PUNTARENAS
GUAYAQUIL
KIRSTIN
JOYCE
IONE
LORRAINE
160°
150°
140°
130°
120°
110°
100°
90°
80°
40°
30°
20°
10°
0°
10°

Figure 5. -- Streamline analysis of the wind field on August 24, 1974. The short arrows with numbers plotted near their heads represent observations of direction and speed, in knots, reported by fishing and merchant vessels. The heavy dashed line marks a portion of the subpoint track of NOAA-3 at the time the satellite picture in figure 6 was taken.

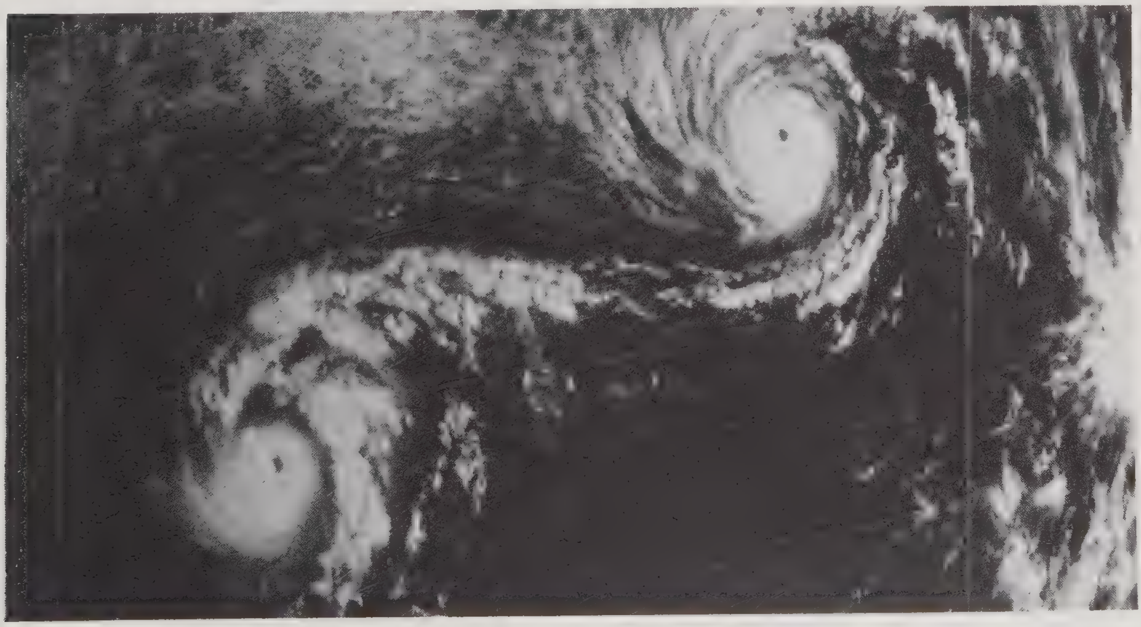

Figure 6. --Weather satellite picture taken with the very high resolution radiometer on NOAA-3, at about 1750 on August 24, 1974. The picture was received and processed at the San Francisco Satellite Service Field Station of the National Environmental Satellite Service.

FAX advisory charts for the eastern tropical Pacific are similar to those developed at SWFC (figs. 1 and 2), with some differences in format, such as the use of symbolic cloud images to denote squally areas, and streamlines instead of discrete wind arrows to denote the wind field, without an explicit delineation of the ITCZ. The NWS sea-state forecast charts also contain swell period in addition to swell height and wave height. The entry of NWS brought full 7-day coverage to the FAX advisory service, which formerly excluded weekends.

Marine forecasters at the San Francisco WSFO have the advantage of support from the NESS Satellite Field Service Station (SFSS), which is colocated with WSFO. The SFSS is equipped and staffed to receive, process, and interpret on a near real-time basis all satellite data, including output from the very high resolution radiometers (fig. 6). Thus, NWS will be assured of high-quality, up-to-date satellite imagery for use in forecasting conditions in the eastern tropical Pacific.

Radio facsimile transmission is also being used in the albacore tuna fishery investigations at the SWFC to send sea-surface temperature information to albacore fishermen. Weekly sea-surface temperature charts are prepared for the region 30° to 50°N, and seaward from the North American west coast to 140°W. Approximately 20 albacore fishing boats are equipped with facsimile recorders and are cooperating in an experimental effort to determine the value of sea temperature information to fishing strategy. The charts are broadcast from station WWD on Friday mornings during the albacore fishing season, May to October.

The FAX program was originated to obtain environmental data for fishery research and to provide fishermen with advisory information which might be of use in their fishing operations. Favorable reaction to the program stimulated increasing participation to the extent that communications are becoming a limiting factor in the amount of real-time data the program can yield. Such data, however, are certain to become more and more valuable as a consequence of the growing concern about and attention to the ocean's role in predicting climatic changes. The scope of global environmental monitoring essential to climate prediction is such that all systems of data collection must be utilized as fully as possible, including those involving cooperating fishing vessels. The continued development of data communications systems using satellites can be expected to lead to more efficient and reliable means of providing ships at sea with environmental analyses and forecasts in exchange for observational data.

WE OF NOAA ARE MAKING USE OF THIS SMALL AMOUNT OF SPACE TO EXTEND OUR THANKS TO ALL THE SHIPS' OFFICERS WHO ROUTINELY TAKE SHIPBOARD WEATHER OBSERVATIONS. TO US, THESE EXCELLENT OBSERVATIONS ARE PRICELESS. WE CERTAINLY DO APPRECIATE RECEIVING THEM ON A REGULAR BASIS.

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EARLY LARVAE OF THE DIAMOND TURBOT, *HYPSOPSETTA GUTTULATA*[1]

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A developmental series of larvae of *Hypsopsetta guttulata* collected in San Francisco Bay is described. These larvae are very similar to *Pleuronichthys* turbots and distinguishing characters which separate larval forms of *Hypsopsetta* from *Pleuronichthys* are discussed. Occurrences of *H. guttulata* eggs and larvae indicate an extended spawning period from early June through mid-October.

INTRODUCTION

The most abundant pleuronectid larva collected to date in a current study of the fish eggs and larvae of Richardson Bay, California, presented a problem. At first the larvae, especially the specimens with the yolk-sac absorbed, appeared to be one of the *Pleuronichthys* species, of which two (*P. decurrens* and *P. verticalis*) were known to be in the San Francisco Bay. Many identifying characters for *Pleuronichthys* spp. established by Budd (1940), however, did not agree with my specimens. The most obvious were the small size of yolk-sac larvae and the presence of oil globules in the yolk. The dilemma was presented to E. H. Ahlstrom of the NMFS Southwest Fisheries Center, who was able to identify the series of specimens as larvae of the diamond turbot, *Hypsopsetta guttulata.*

The diamond turbot is not tabulated separately in commercial landings but is included with turbots of the genus *Pleuronichthys.* Together they constitute a minor part of the commercial catch. The diamond turbot is often caught by coastal sport fishermen. This reflects the fish's habitat; it is commonly found in shallow bays and tidal flats and on muddy or sandy bottoms (Baxter 1960). This species ranges from Cape Mendocino to Cape San Lucas, Baja California, and in the Gulf of California. The larval specimens described herein are from the northern extent of the range of *H. guttulata* but early records (Jordan and Gilbert 1880) show that it has long been a resident of San Francisco Bay. Compared to the *Pleuronichthys* turbots, little is known of the life history of the diamond turbot, especially its reproductive habits.

Limbaugh (1955) stated that the pelagic eggs are released during summer and fall. Eggs from running ripe diamond turbots were taken by Limbaugh during the summer and similar eggs were taken repeatedly in plankton collections made off the Scripps Institution of Oceanography pier during the summer of 1952 (Orton and Limbaugh 1953).

The purpose of this paper is to describe the early life history stages of *H. guttulata* and to give characters that will readily separate it from the larvae of the two *Pleuronichthys* species whose adults occur in San Francisco Bay. The description is handicapped by the lack of a complete developmental series. There were no specimens obtained between 5.8 mm

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[1] Accepted for publication July 1974.

and 11.4 mm (0.23 and 0.45 inch). Therefore, the study concentrates on the younger larvae. Juvenile and adult specimens used in this study were obtained from field collections in San Francisco Bay and from the collection of the California Academy of Sciences.

METHODS

The larval specimens used for this description were collected in Richardson Bay, California, which is an approximate 11.0 km^2 (4.25 mile^2) shallow embayment located immediately to the north of the entrance to and within San Francisco Bay. Two methods were used to catch the diamond turbot. A standard 0.5 meter plankton net was towed at randomly selected stations throughout Richardson Bay, and two stationary channel nets, modified from a design of Lewis, et al (1970), were fished simultaneously. One channel net was positioned midway up the Bay and the other near the entrance to the Bay. All nets had a mesh aperture size of 333 micra.

A total of 135 specimens were examined in this study, 95 of which were larvae. The larvae were preserved in 5% buffered formalin, while the juvenile and adult fish were preserved in 40% isopropyl alcohol. Morphometric measurements followed those described by Ahlstrom and Ball (1954) and were made with an ocular micrometer. I selected the illustrated specimens to represent stages of development. The illustrations are literal, drawn by means of a camera lucida.

The meristic data were taken from either specimens stained with alizarin or from x-ray photographs.

The following description is organized by character according to the approach used by Ahlstrom and Ball (1954). Each character is followed through its development. Pigmentation is presented first followed by morphology and meristics.

PIGMENTATION

The discussion on pigmentation is limited to those melanophores visible in the preserved specimens. It is possible other body pigments are present in diamond turbot larvae but are lost in formalin preservation. The pigmentation varied within any given size class as might be expected for a species with heavy pigmentation. Throughout the entire series the larvae exhibited generally heavy body pigmentation on the anterior $\frac{3}{4}$'s of the body of yolk-sac larvae and extending $\frac{4}{5}$'s of the body length in 5 mm larvae. The most notable variation in pigment was the range of development of patches of scattered fine melanophores located along the dorsal and ventral midlines posterior to the anus. In younger forms, these patches ranged from barely detectable spots on the bases of the finfolds to occasionally a definite triangular patch in one or both finfolds. The older larvae did not exhibit any patches extending onto the finfold, but dark strips of fine spots were clearly visible.

Newly hatched larvae (Figure 1a) completely lacked eye pigment. The head and body were pigmented. The head melanophores were discrete stellate units while the body exhibited fine stippling at 50 x magnification. The yolk-sac was devoid of pigment except for approximately 10–15 stellate melanophores on the surface of the large oil globule.

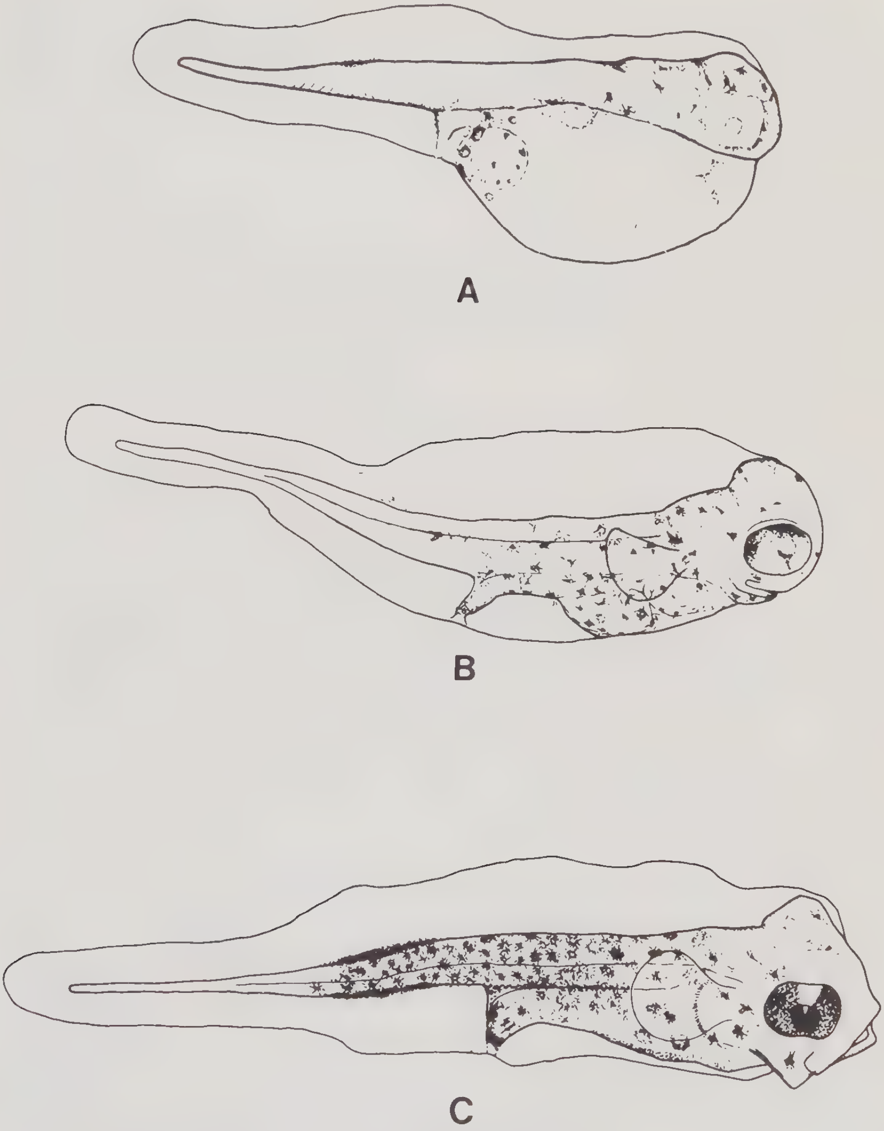

FIGURE 1. Diamond turbot. A, 1.7 mm; B, 212 mm; C, 216 mm.

As the yolk was absorbed and the gut became functional, the pigment spread ventrally over the yolk-sac. The hindgut enlarged and pigment was seen over its ventral flexion to the anus. Melanophores persisted on the oil globule. An interconnecting network of stellate melanophores was present over most of the anterior half of the body. The postanal patches on the dorsal and ventral midlines were now visible. In most specimens these were seen only as intensification of the fine pigment spots near the base of the finfold.

Eye pigmentation developed along the dorsal rim of the eye (Figure 1b). There was still some yolk visible at this stage and the mouth was well developed with up to 10 stellate melanophores along the margin of the dentary. The past-anal patches lessened in size in larger specimens and were routinely seen as concentrations of midline pigment (Figure 1c). The body became covered with discrete large stellate melanophores. Several spots were also visible in the isthmus. This general pattern continued into larger specimens (Figure 2a).

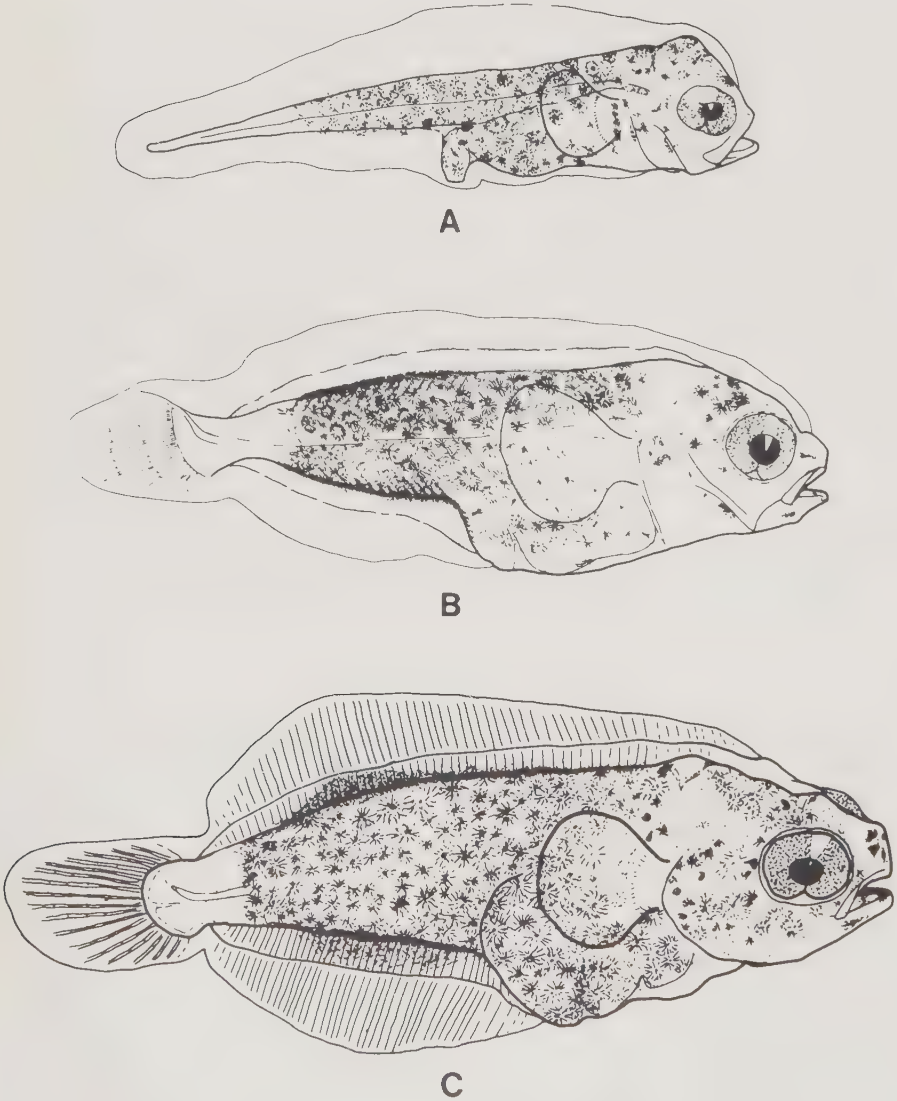

FIGURE 2. Diamond turbot larvae. A, 3.8 mm; B, 4.9 mm; C, 5.8 mm.

The more developed larvae around 4.0 to 4.9 mm were distinguished by the elongate patches which now were densely pigmented but still confined to the base of the developing vertical fin anlage. The head had less surface pigment spots but imbedded melanophores were visible, especially at the nape.

The metamorphosing larvae (Figure 2c) continued these pigment patterns. The median patches were more extensive, spreading onto the pterygiophore bases of the dorsal and anal fins. The specimens at this stage of development presented different appearances depending on the extent of expansion or contraction of the melanophores. Almost the entire body exclusive of the outer fin margins and the posterior portion of the body was covered with stellate melanophores.

Meristic characters easily distinguish metamorphosed juveniles. These characters are presented in Table 1. All juvenile specimens had a total of 35 vertebrae; 12 abdominal and 23 caudal. The dorsal fin averaged 71 rays and the anal fin 50 rays. The caudal fin averaged 19 rays. The eyed side was densely pigmented over the entire body. Dark spots were scattered on both sides and ended prior to the caudal penduncle. Pigment extended onto the vertical fins.

MORPHOMETRY AND MERISTICS

The newly hatched larvae averaged 1.6 mm (0.063 inch) standard length (S.L.) and appeared deep bodied because of the large yolk-sac. The oval shaped yolk-sac contained unsegmented yolk with numerous oil globules, the largest positioned to the rear of the yolk-sac. The single large oil globules averaged 0.14 mm (0.005 inch) in diameter. As the yolk was absorbed, the yolk-sac appeared more ovate and the head and hindgut more outlined. By approximately 2.2 mm (0.087 inch) S.L., the yolk was more than ½ absorbed. The oil globule now averaged around 0.06 mm (0.002 inch). Larvae ranging 2.3 to 2.4 mm (0.090 to 0.094 inch) had consumed nearly all their yolk.

As the yolk was consumed, the gut and mouth became more developed. Newly hatched larvae had no functional mouth and the hindgut leading to the anus appeared as a thin transparent tube extending ventrally through the finfold. Gut development was most evident in the bulging or enlargement proceeding ventrally to the anus, accompanied by heavy gut pigmentation. By 2.3–2.4 mm (0.090 to 0.094 inch) S.L., the gut was functional and food was seen in the intestine. In general, the gut length shortened relative to body length in the larvae; at metamorphosis the snout to anus length was approximately 35% S.L. (Figure 3).

Body shape became more fusiform as yolk absorption progressed. Some specimens slightly hunched over the yolk-sac, but this disappeared with yolk absorption. With the thickening of the gut, the development of the mouth and enlargement of the head, the body deepened in relation to its length (Figure 3). The specimens around 3.8 mm to 4.9 mm began to exhibit the compressed flatfish form. The illustrated larvae display the gradual rotation of the gut anteroventrally with a characteristic sag to the stomach. The metamorphic specimens had a rounded appearance to the gut. Their bodies were more compressed. Throughout the developmental series the myomeres were difficult to see mostly because of the intense pigmentation.

The head of the hatchling showed a midbrain bulge separated from forebrain and medulla which is typical of many pleuronectid larvae. By 2.4 mm, it appeared as a large dome which continued throughout the series. The fore and hindbrain sections could be seen also at these sizes. The head increased in overall relative size throughout development finally reaching approximately ⅓ of the body length, then it

TABLE 1.—**Average Morphometrics and Meristics of Larval and Juvenile Diamond Turbot, *Hypsopsetta guttulata***

	Average Morphometrics (mm)						Average Meristics		
Standard length	Number examined	Standard length	Head length	Eye diam.	Depth at base of pectoral	Snout to anus	Vertebrae	Dorsal	Anal
1.0–1.4	3	1.4	.30	.17	ys*	.8			
1.5–1.9	36	1.7	.36	.19	.42	1.0			
2.0–2.4	44	2.2	.46	.20	.44	1.1			
2.5–2.9	1	2.5	.53	.22	.45	1.3			
3.0–3.4	2	3.2	.67	.30	.65	1.7			
3.5–3.9	3	3.6	.94	.35	.97	2.0			
4.0–4.4									
4.5–4.9	4	4.7	1.31	.46	1.33	2.5			
5.0–5.9	2	5.8	1.80	.56	1.80	2.7			
11.0–11.9	1	11.5	4.5	2.4	6.6	4.6	35	75	48
12.0–12.9	1	12.8	4.4	1.4	6.9	4.5	35	66	50
13.0–13.9	2	13.4	4.6	1.9	7.6	4.8	35	72	52
14.0–14.9	3	14.5	5.2	1.5	8.0	5.4	35	71	49
15.0–15.9	5	15.5	5.4	1.7	8.7	5.8	35	70	51
16.0–19.9	13	17.6	5.7	2.0	9.4	6.1	35	71	52
20.0–49.9	12	31.3	9.9	2.9	17.4	11.7	35	67	50
50.0	3	73.3	20.3	5.3	35.7	23.0	35	72	51

* Yolk-sac present

decreased slightly as the body deepened (Figure 2). The mouth was inferior in position until 3.5–3.9 mm when it became terminal. The larvae around 5.8 mm exhibited asymmetric growth, with the left eye

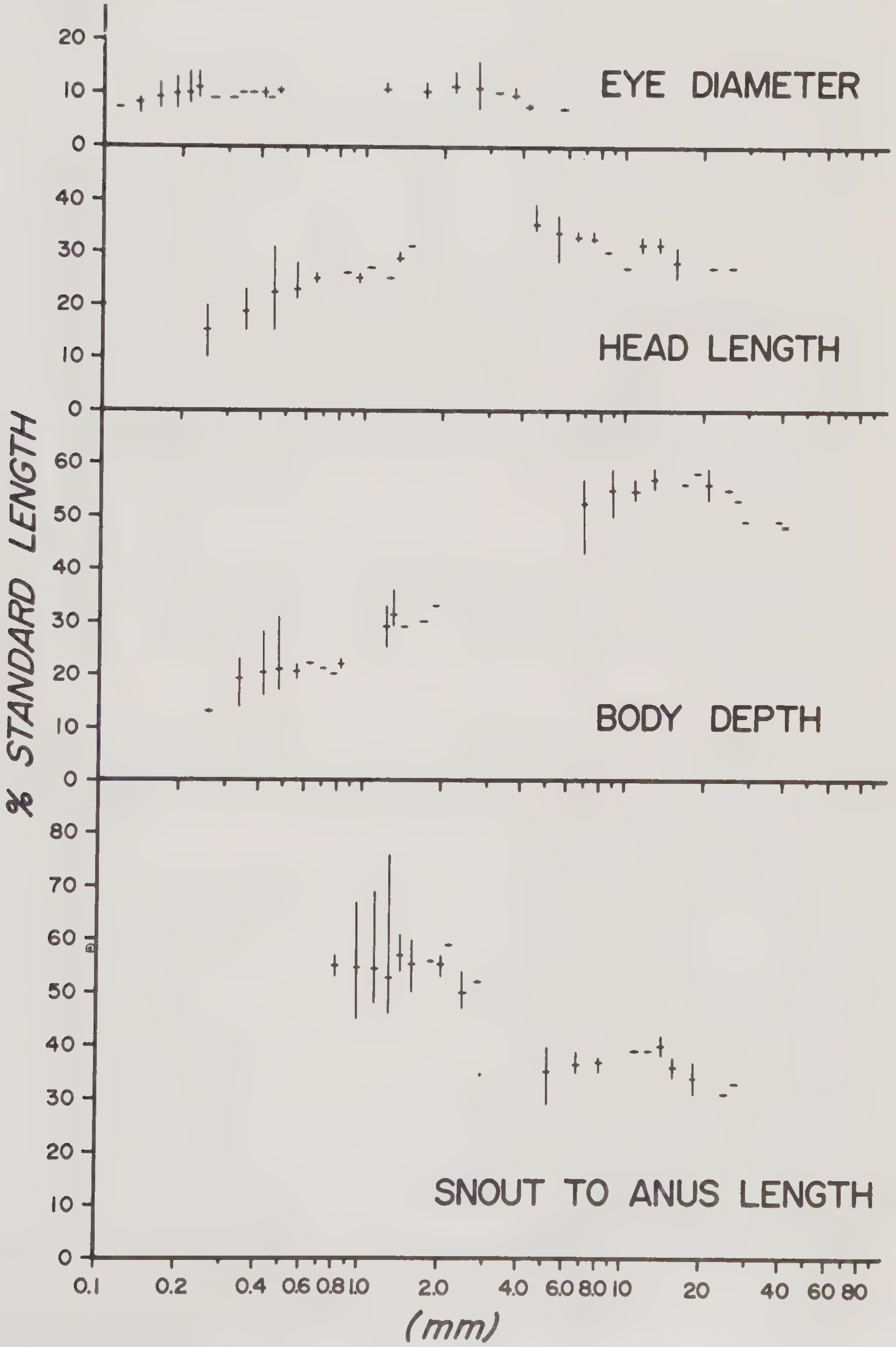

FIGURE 3. Morphometric proportions (in logarithmic scale) of the diamond turbot, plotted as percentages of standard length.

in the midst of migration to the right side. Eye diameters remained much the same in relation to body length throughout development (Figure 3).

The finfold began at the forehead and extended posteriorly around the tail and forward to the yolk-sac or gut. It remained complete and translucent throughout development until around 3.8 mm when the anlagen of the dorsal and anal fins and the caudal fin were seen forming. At hatching the pectoral fin bud was visible on the dorsal aspects of the yolk-sac. By approximately 2.4 mm, the pectoral fins appeared as small lateral projections.

The 4.9 mm larvae possessed nearly developed dorsal and anal fins but the fin ray counts were not complete. Likewise, the metamorphosing larvae did not have complete dorsal and anal fin development, but the rays were more discernible. The caudal fin developed simultaneously with the dorsal and anal fins. The upward flexion of the caudal notochord occurs at about 4.0 mm S.L. The hypural cartilages and the full complement of caudal rays were visible in the metamorphic specimens (Figure 2c). In these advanced larvae, the pterygiophore primordia appeared as longitudinal ridges along the bases of these fins. The smallest juvenile specimen (11.5 mm) did show complete vertical fin ray development.

DISCUSSION

From occurrences of the larvae, *Hypsopsetta guttulata* appeared to have an extended spawning period. Larvae, and what I believe to be the pelagic eggs of the diamond turbot, were collected from early June through mid-October.

These eggs averaged 0.80 mm in diameter with usually one large oil globule (average 0.14 mm diameter) and numerous other globules scattered throughout the yolk. They can easily be distinguished from *Pleuronichthys* eggs by the absence of the hexagonal pattern on the chorion and the presence of oil globules.

It is very easy to confuse *H. guttulata* larvae with *Pleuronichthys* larvae, especially with the similarity in pigmentation and morphology. There are no other known larvae in this geographical area which have such heavy pigmentation and which might be confused with turbot larvae. So differentiation needs to be made between the larvae of the different turbots which might occur in the San Francisco Bay area.

In general, the *Pleuronichthys* larvae are larger than *Hypsopsetta* larvae in the early stages of development. *P. verticalis* is the smallest at hatching being 3.16 mm (0.12 inch) long (Budd 1940). Even allowing for shrinkage during preservation, *Hypsopsetta* larvae would not exceed about 2.00 mm (0.08) at hatching. Yolk-sac larvae of *P. verticalis* have a notable crest not as pronounced in the diamond turbot. Another distinguishing characteristic for the young is the presence of oil globules in the yolk. The finfold pigment patches found in both *P. verticalis* and *P. decurrens* are not as developed or as consistently present in the diamond turbot. Only the very small *Hypsopsetta* larvae (2.4 mm) had finfold patches. The mottled turbot, *P. coenosus*, is separated most easily because it is very large at hatching (5.54 mm) and has heavy pigmentation throughout its finfold.

It can be seen that various turbot larvae are best separated by pigmentation (especially in the finfold), and relative size at which structures develop in post yolk-sac larvae.

ACKNOWLEDGEMENTS

I wish to acknowledge the valuable advice, instruction, and generous time E. H. Ahlstrom and H. G. Moser of the Southwest Fisheries Oceanography Center offered me during the course of this study. I also would like to thank the California Academy of Sciences, especially Lillian Dempster, for providing equipment and specimens.

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FITTING THE GENERALIZED STOCK PRODUCTION MODEL BY LEAST-SQUARES AND EQUILIBRIUM APPROXIMATION[1]

WILLIAM W. FOX, JR.[2]

ABSTRACT

A least-squares method for fitting the generalized stock production to fishery catch and fishing effort data which utilizes the equilibrium approximation approach is described. A weighting procedure for providing improved estimates of equilibrium fishing effort and an estimator of the catchability coefficient are developed. A computer program PRODFIT for performing the calculations is presented. The utility and performance of PRODFIT is illustrated with data from a simulated pandalid shrimp population.

The production model approach to fish stock assessment is simply an adaptation of the Lotka-Volterra population equations into the situation of a population exploited by man. The earliest such adaptation was by Graham (1935) in assessing the potential production from North Sea fish stocks. The major development of this approach in fisheries management, though, is due to Schaefer (1954, 1957) who initiated it as a management tool for the yellowfin tuna fishery of the eastern tropical Pacific Ocean. While there has been an attempt at a detailed extention of the production model approach to multispecies fisheries (Lord 1971), the usual application has been on a single species stock.

Mathematical formulation of the production model begins with the general differential equation

$$dP/dt = P_t g\,(P_t) - P_t h(f_t) \qquad (1)$$

where P_t is the population size at time t, $P_t g(P_t)$ is the population production function encompassing the effects of reproduction and natural mortality (and growth in weight if biomass is the population unit), and $h\,(f_t)$ is the fishing mortality coefficient exerted by f_t units of fishing effort. Fishing effort is assumed to be standardized from nominal fishing effort such that $qf_t = F_t$, where F_t is the instantaneous coefficient of fishing mortality and q is a constant (the catchability coefficient), giving $qf_t P_t = dC/dt$, the rate of catch. At equilibrium, that is $dP/dt = 0$, the catch rate equals the production rate such that an equilibrium yield, Y, is obtained

$$Y = qfP = Pg(P). \qquad (2)$$

The most general assumptions about the form of $P_t g\,(P_t)$ are that it should 1) approach zero as P_t approaches some environmental capacity, $P_{\max}$, and 2) increase to some maximum at a population size smaller than the environmentally limited size. Practically, the function should be simple, since in any case the approach is a gross simplification of population dynamics. The most flexible, simple function advanced for $P_t g\,(P_t)$ is a simple case of Bernoulli's equation (Chapman 1967; Pella and Tomlinson 1969)

$$P_t g(P_t) = HP_t^m - KP_t \qquad (3)$$

where H, K, and m are constant parameters.[3] Equation (3) includes the logistic function when $m = 2$ (Schaefer 1954, 1957) and the Gompertz function $[K'P_t - H'P_t \ln P_t]$ as $m \rightarrow 1$ (Fox 1970). Equation (3), hereafter referred to as the generalized stock production model after Pella and Tomlinson (1969), approaches zero at $P_{\max} = (K/H)^{1/(m-1)}$ and has a maximum $P_{\text{opt}} = [m^{1/(1-m)}] \cdot P_{\max}$.

Three equilibrium relationships can be derived by the substitution of Equation (3) in Equation (2) to obtain

1) Yield and population size

$$Y = HP^m - KP, \qquad (4)$$

2) Population size and fishing effort

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[1] Adapted, in part, from a Ph.D. dissertation, College of Fisheries, University of Washington, Seattle, WA 98195.

[2] Southwest Fisheries Center, National Marine Fisheries Service, NOAA, P.O. Box 271, La Jolla, CA 92037.

[3] When formulated as in Equation (3), H and K are positive for $m < 1$, but are negative for $m > 1$.

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$$P = \left(\frac{K}{H} + \frac{q}{H} f\right)^{\frac{1}{m-1}} \qquad (5)$$

3) Yield and fishing effort

$$Y = f\left(\frac{Kq^{m-1}}{H} + \frac{q^{m}}{H} f\right)^{\frac{1}{m-1}} \qquad (6)$$

The critical points, useful as management implications and previously derived by Pella and Tomlinson (1969), are:

$$f_{\text{opt}} = K\left(\frac{1}{m} - 1\right)/q \qquad (7)$$

$$P_{\text{opt}} = [K/(mH)]^{\frac{1}{m-1}} \qquad (8)$$

and

$$Y_{\max} = H[K/(mH)]^{\frac{m}{m-1}} - [K^{m}/(mH)]^{\frac{1}{m-1}}, \qquad (9)$$

where f_{opt} is the amount of fishing effort required to produce $Y_{\max}$, the maximum sustainable average yield (MSAY),[4] and P_{opt} is the equilibrium population size obtained at f_{opt}. Figure 1 demonstrates the flexibility of the generalized stock production model with three values for m (0.5, 2.0, 4.0); each curve has the same value for $P_{\max}$ and $Y_{\max}$.

In utilizing the production model for analysis of the status of a particular population, the usual basic assumptions are that 1) the model is being applied to a closed single unit population, 2) the concept of equilibrium conditions[5] applies to the population under analysis, and 3) the age-groups being fished have remained, and will continue to remain, the same. If one is able to obtain data which represent equilibrium conditions at three or more population levels, then no additional assumptions are needed to fit the production model. In most fishery data sets, however, no real period of equilibrium conditions will exist. Using data from the transitional states of a population requires the additional assumptions that both 1) time lags in processes associated with population change and 2) deviations from the stable age structure at any population level have negligible effects on the production rate, $P_t g(P)_t$ (Schaefer and Beverton 1963).

Schaefer (1954, 1957) pioneered the use of transitional state data for fitting a production model (the logistic form) to catch and fishing effort data. Schaefer's (1957) method for estimating the parameters consisted of approximating differential equation (1) with two finite difference equations and then iteratively solving them. Pella and Tomlinson (1969) greatly improved upon Schaefer's method by demonstrating that a catch history of a fishery could be predicted from the fishing effort history, initial estimates of the production model parameters, and the integrated form of Equation (1). Then final parameter estimates could be obtained by a pattern search routine which finds those parameters which minimize the residual sum of squared differences between

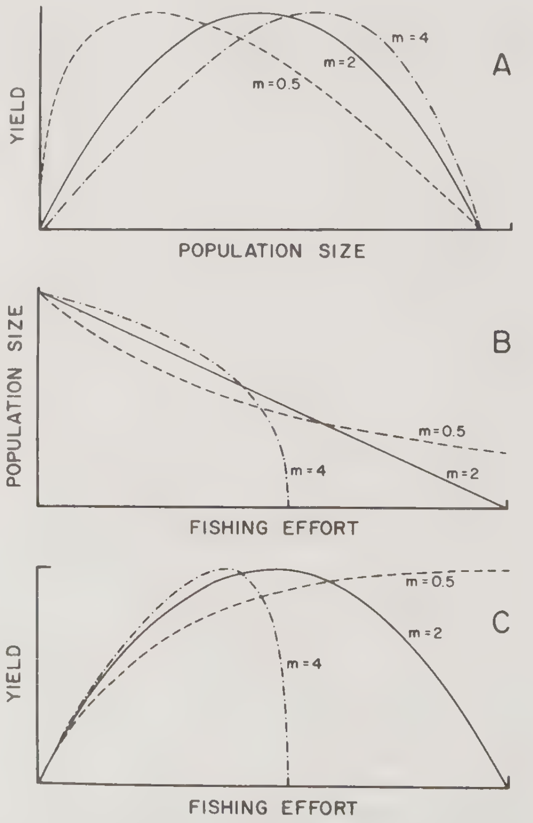

FIGURE 1.—Equilibrium relationships of the generalized stock production model for three values of m. (A) Equilibrium yield and population size; (B) population size and fishing effort; (C) equilibrium yield and fishing effort.

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[4] $Y_{\max}$ is usually referred to as the maximum sustainable yield (MSY). The term MSY, however, does not convey that in reality the yield will fluctuate due to changes in the population even if the fishing effort and catchability coefficient remain constant. Hence, the "equilibrium yield" curve represents a curve of yield that is sustainable at some average level.

[5] The definition of equilibrium adopted here, essentially that of Beverton and Holt (1957), is: given a constant rate of fishing, including zero, a population will achieve a state where, on the average, it will not change in size or characteristics.

the observed and predicted catches. While these two estimation methods are very different in their degree of sophistication, they are fundamentally the same in that both methods utilize the prediction of population transitional state changes by the production model. For convenience, this approach will be subsequently referred to as the transition prediction approach.

Gulland (1961) established a second approach to fitting production models with transitional state data. Gulland's approach estimates the level of fishing effort which, if equilibrium obtained, would produce, on the average, the observed level of catch per unit effort in each year of the fishery. Then the set of paired catches per unit effort and estimated equilibrium fishing effort units are fitted to one of the equilibrium relationships given by, or derived from, Equation (4), (5), or (6). This approach will be referred to subsequently as the equilibrium approximation approach.

Clearly, the transition prediction and equilibrium approximation approaches are basically different. The transition prediction approach is obviously intimately based upon the transition state population assumptions. On the other hand, the degree to which the equilibrium approximation approach is dependent on these assumptions is unclear. This paper presents a least-squares method and a computer program PRODFIT, which uses the equilibrium approximation approach to estimate the parameters (and indices of their variability) of the generalized stock production model. A weighting procedure for providing improved estimates of equilibrium fishing effort and an estimator of the catchability coefficient are developed. The utility and performance of computer program PRODFIT is illustrated by fitting deterministic and stochastic data from a simulated pandalid shrimp population. Some cursory comparisons between the equilibrium approximation and transition prediction approaches are made by repeating the pandalid shrimp simulated data fits with GENPROD, the computer program written by Pella and Tomlinson (1969).

FITTING METHOD

The equilibrium approximation approach was first outlined in Gulland (1961), but is more fully explained in Gulland (1969:120). Gulland's method involves relating the annual catch per unit effort in year i, U_i, to the fishing effort averaged over some number of years, T. Gulland (1961) first defined T as the mean life expectancy of an individual in the fishable population, or Z^{-1}, where Z is the instantaneous total mortality coefficient and the value of Z^{-1} is rounded off to the nearest integer. Subsequently, Gulland (1969) defined T as the average fishable duration of a year class (again to the nearest whole year)—he provided the following example: if recruitment is at 4 yr and if most of the catch in year i consists of 4 to 9 yr-old fish, then the average fishable duration is about 3 yr so U_i would be related to an average of f_i, f_{i-1} and f_{i-2}. The general formulation for the averaged fishing effort in year i is

$$\bar{f}_i = \frac{1}{T} \sum_{j=i-T+1}^{i} f_j \tag{7}$$

A discussion of the rationale for, and performance of, Gulland's averaging method is given by Gulland (1969:120).

Weighted Average Fishing Effort Method

In this paper a different tack is taken which results in approximating equilibrium fishing effort with a weighted average. The catch per unit effort of the incoming year class j in year i, U_{ij}, is related to the amount of effort in year i; that of the previous year class, $U_{i,j-1}$, is related to the fishing effort in years i and $i-1$; that of the year class which entered 2 yr previously, $U_{i,j-2}$, is related to the fishing effort in years i, $i-1$, and $i-2$; and so forth. The catch per unit effort of the total fishable population, assuming equal catchability, is

$$U_i = U_{i,j} + U_{i,j-1} + U_{i,j-2} + \cdots + U_{i,j-k+1}$$

for k year classes. For the simplest case where the incoming year class is recruited at the beginning of each year's fishing season, therefore,

$$U_i \sim \left\{k \cdot f_i + (k-1) \cdot f_{i-1} + \cdots + f_{i-k+1}\right\}. \tag{8}$$

Equation (8) suggests a weighted average of fishing effort over the total number of years that a year class contributes significantly to the fishery, or

$$\bar{f}_i = \left\{k \cdot f_i + (k-1) \cdot f_{i-1} + \cdots + f_{i-k+1}\right\} / \left\{k + (k-1) + \cdots + 1\right\}. \tag{9}$$

An arithmetic average rather than a geometric average is suggested because most applications are on catch in weight, i.e. while year classes decline exponentially in terms of numbers they concomitantly increase in terms of mean weight per individual.

The weighting procedure can be more precise if it is known when during the year of record that recruitment occurs. For example, if recruitment occurs at midseason during the year of record for a fishable population of three year classes, $\bar{f}_i$ changes from $\left\{3f_i + 2f_{i-1} + f_{i-2}\right\}/6$ to $\left\{2.5f_i + 1.5f_{i-1} + 0.5f_{i-2}\right\}/4.5$. Further precision is gained if k is varied from year to year with the level of fishing effort, since at high fishing rates fewer year classes will contribute significantly to the catch than at low fishing rates. Further adjustments can be made for unequal catchability among the year classes.

The unweighted method of averaging the fishing effort, Equation (7), and the new weighted method, Equation (9), will be compared in a subsequent section of this paper.

Estimation Procedure

Gulland (pers. commun.)[6] prefers an eye-fitted curve for estimating the equilibrium relationship between U_i and f_i because of the oversimplification of the method and the errors associated with usual catch and effort data. However, these reasons should not defer the seeking of a more precise method of fitting a curve nor the taking advantage of error estimation schemes, if the simplifications and assumptions are kept in mind. On the contrary, it will be demonstrated that, at least for some controlled conditions, the equilibrium approximation approach provides reasonably good results.

Equation (5) may be written in terms of catch per unit effort and averaged fishing effort as

$$U_i = [(Kq^{m-1}/H) + (q^m/H)\bar{f}_i]^{1/(m-1)} \qquad (10)$$

or simply

$$U_i = (\alpha + \beta\bar{f}_i)^{1/(m-1)}. \qquad (11)$$

Equation (11) is a nonlinear function with three parameters which does not require simultaneous estimation of the catchability coefficient, q. The critical points in terms of the parameters of Equation (11) are

$$f_{\text{opt}} = (\alpha - \alpha m)/(m\beta) \qquad (12)$$

$$U_{\text{opt}} = (\alpha/m)^{1/(m-1)} \qquad (13)$$

and

$$Y_{\max} = \frac{(\alpha - \alpha m)\,(\alpha/m)^{1/(m-1)}}{m\beta} \qquad (14)$$

Given the data set $\left\{U_i, \bar{f}_i\right\}$, where $i = 1\ldots n$ observations, the least-squares criterion for estimating the parameters α, β, and m is to minimize the function

$$S = \sum_{i=1}^{n} W_i(U_i - \hat{U}_i)^2 \qquad (15)$$

where the W_i are statistical weights, and $\hat{U}_i$ are the predicted equilibrium catches per unit effort from Equation (11). The statistical weights,

$$W_i = (\hat{U}_i)^{-2}, \qquad (16)$$

are derived from the assumption of the multiplicative error structure as suggested by Fox (1971). Weighting as in Equation (16) will usually give the greatest weight to observations at the highest level of averaged fishing effort; in many cases these also will be the most recent observations. Giving greater weight to observations at high effort levels will tend to give the greatest weight to observations with the greatest temporal and spatial coverage of the population. In addition, giving the greatest weight to the most recent data is especially advantageous when approaching the $Y_{\max}$ level during a period increasing fishing effort because the observations nearest the $Y_{\max}$ level receive the greatest weight.

Up to now no mention has been made on the estimation of the catchability coefficient, q. This is because experience with GENPROD and stochastic simulation studies have indicated that poor results are frequently obtained from the simultaneous estimation of q (Pella and Tomlinson 1969; Fox 1971). Once that α, β, and m have been estimated, q may be treated as a conditional probabilistic variable and estimated as a mean value. Two tacks were selected, the difference method and the integral method.

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[6] John A. Gulland, Food and Agricultural Organization, Rome, Italy.

The difference method involves writing Equation (1) as a finite difference equation for the production model in terms of catch per unit effort and the estimates for α. β, and m as

$$\frac{1}{q}\frac{\Delta U_i}{\Delta t} = \frac{1}{\hat{\beta}} U_i^{\hat{m}} - \frac{\hat{\alpha}}{\hat{\beta}} U_i - f_i U_i \tag{17}$$

for each year i; Δt is taken as one unit, Equation (17) is divided through by U_i, summed over the $n - 2$ yr that ΔU_i can be estimated, and then solved for $\hat{q}_S$,

$$\hat{q}_S = [\sum_{i=2}^{n\ \ 1} \frac{\Delta \hat{U}_i}{U_i}] / [\frac{1}{\hat{\beta}} \sum_{i=2}^{n-1} U_i^{\hat{m}-1} - (n-2)\frac{\hat{\alpha}}{\hat{\beta}} - \sum_{i=2}^{n-1} f_i] \tag{18}$$

where

$$\Delta \hat{U}_i = (U_{i+1} - U_{i-1})/2. \tag{19}$$

This method has provided reasonable estimates with the logistic ($m = 2$) and Gompertz ($m \rightarrow 1$) forms of the production model for several fisheries (Fox 1970).

Pella and Tomlinson (1969) observed that Equation (19) can be a poor estimator of the change in stock size during year i under certain circumstances. The integral method avoids this problem by writing Equation (17) as a differential equation

$$\frac{dU}{U(-\frac{\hat{\alpha}}{\hat{\beta}} - f^* + \frac{1}{\hat{\beta}} U^{\hat{m}-1})} = q\,dt, \tag{20}$$

where f^*, the effective effort having been exerted between years i and $i+1$, is estimated by

$$\hat{f}^* = (f_i + f_{i+1})/2. \tag{21}$$

The integral of Equation (20) after rearranging some terms is

$$\hat{q}_i = \ln[\,|(zU_i^{1-\hat{m}} + \frac{1}{\hat{\beta}})/(zU_{i+1}^{1\ \ \hat{m}} + \frac{1}{\hat{\beta}})|\,]/(z\hat{m} - z) \tag{22}$$

where

$$z = -\hat{\alpha}/\hat{\beta} - \hat{f}^*.$$

The fact that Equation (22), as an estimator of q, gives negative values when the stock changes in one direction, depending on whether m is greater or less than 1, is remedied by taking the absolute value of q. Also, since q is constrained against being less than zero, the geometric mean will probably be a better estimator than the arithmetic mean (this will be demonstrated to be so in at least one case), such that

$$\hat{q}_I = e^{\sum_{i=1}^{n-1} \ln|\hat{q}_i|/(n-1)} \tag{23}$$

becomes the integral estimator.

Variability Measures

Some measure of the variability of the parameter estimates can be made using the "delta" method (Deming 1943). If S is the weighted residual sum of squares for the final parameter estimates, a variability index matrix, V, is computed by

$$V = (X'WX)^{-1} S/(n-3) \tag{24}$$

where W is an n by n diagonal matrix of the statistical weights, X is an n by 3-parameter matrix of first partial derivatives of Equation (11) with respect to each parameter (given in the Appendix). The diagonal elements of V are variability indices of the parameter estimates and the off-diagonal elements of V are covariability indices. Since Equation (11) is nonlinear, the independent variable is not without error, the errors in the dependent variable are correlated, and the statistical weights are random variables, it is virtually impossible to make probability statements about the accuracy of the parameter estimates (Draper and Smith 1966). However, V gives some index of the variability inherent in the data which is useful largely for comparative purposes between different fisheries and data sets. For convenience, an error index may be formulated as

$$E_{\chi} = [100\sqrt{V(\hat{\chi})}]/\hat{\chi} \tag{25}$$

where $\hat{\chi}$ is the estimated parameter and $V(\hat{\chi})$ is its corresponding variability index. Variability and error indices of $Y_{\max}$, f_{opt}, and U_{opt} also may be computed by the "delta" method (see Appendix) and the elements of V (Equation 24).

Program PRODFIT

A computer program PRODFIT, in FORTRAN IV language, was written to perform the calculations described above. A brief description of the program's options and mode of operation is given below.

DATA INPUT OPTION. *Option 1.*—A catch

and fishing effort history, $\{C_i, f_i\}$, of $i = 1 \ldots n$ years length and a vector of significant year class numbers $\{k_i\}$ are read in. There may be embedded zeros, if they are true zeros and do not simply reflect a lack of information. The only real problem with unreal zeros, however, occurs in the estimation of q. The catch per unit effort vector is computed internally and the averaged fishing effort vector is computed by Equation (9) with SUBROUTINE AVEFF.

Option 2.—If one wishes to compute the averaged fishing effort vector by another method or if data are obtained which represent equilibrium conditions, then this option is selected and the vectors of catch per unit effort and averaged (or equilibrium) fishing effort $\{U_i, \bar{f}_i\}$ are read in directly. No estimate of q can be made, however.

STARTING VALUES OPTION. *Option 1*.—Initial estimates of the parameters are computed in SUBROUTINE INEST and the user provides the starting estimate for m, either 0, 1, or 2. *Option 2*.—Occasionally the data are so variable that INEST does not provide compatible starting values for the parameters. In this case, or in any case, the user may opt to enter directly all the initial parameter estimates.

MODEL OPTION. The user may allow PRODFIT to estimate m to any desired precision. Frequently, however, the data are so variable that no significant reduction in the residual sum of squares is obtained by varying m. The user then has the option to fix m at 2, the logistic model (Schaefer 1957); at 1, the Gompertz model (Fox 1970); or at 0, the asymptotic yield model.

WEIGHTING OPTION. The user may select the statistical weights as Equation (16) or may choose to not weight the observations, i.e., $W_i = 1$ for all i.

CATCHABILITY COEFFICIENT. The catchability coefficient, q, is estimated by Equation (22), but both the geometric and arithmetic averages are computed.

Program PRODFIT uses an adaptation of the same pattern search optimization routine, MIN, as contained in GENPROD (Pella and Tomlinson 1969) to locate the least-squares parameter estimates. A more sophisticated Taylor series approach (Draper and Smith 1966) was attempted initially, but severe distortion of the sum-of-squares space prevented reasonable convergence. In order to facilitate termination of the searching procedure, the sum-of-squares space is searched with m and a transformation of the parameters α and β to

$$U_{\max} = \alpha^{1/(m-1)} \qquad (26)$$

$$Y_{\max} = \frac{(\alpha - \alpha m)(\alpha/m)^{1/(m-1)}}{m\beta} \qquad (27)$$

where $U_{\max}$ is the unexploited population size in terms of catch per unit effort. Neither $U_{\max}$ nor $Y_{\max}$ change greatly with moderate changes in m.

The output of PRODFIT provides a listing of the input data, the transformed data, initial parameter estimates, the iterative solution steps, the final estimates of α, β, and m and their variability indices, the management implications of the final model $U_{\max}$, U_{opt}, f_{opt}, and $Y_{\max}$ and their variability indices, the observed and predicted values and error terms, and estimates of the catchability coefficient, q.

A listing of program PRODFIT and a user's guide are available on request from the author.

COMPARATIVE EXAMPLES OF THE EQUILIBRIUM APPROXIMATION METHODS

Two methods of averaging fishing effort which attempt to approximate equilibrium conditions have been presented, the unweighted method (Equation 7) and the new weighted method (Equation 9). In order to compare these two methods, catch histories for a simulated pandalid shrimp fishery (Fox 1972) were generated using a generalized exploited population simulation model GXPOPS (Fox 1973). It should be noted, however, that the comparisons are, for the most part, simply illustrative. It is virtually impossible to demonstrate conclusively which is the better method because there is an infinite choice of life histories, parameter values, fishing effort histories, and stochastic variation representations.

Equilibrium values for the unexploited population biomass in terms of catch per unit effort ($U_{\max}$), the maximum equilibrium yield ($Y_{\max}$), and optimum fishing effort (f_{opt}), were determined empirically by running the simulation model

(Table 1). The catchability coefficient, q, was assumed to be 1.0. Figure 2 presents the equilibrium values of catch per unit effort and yield at fishing effort values ranging from 0.0 to 1.3 for the simulated shrimp population. Above $f = 1.3$ the population level did not stabilize in 25 yr of simulation and at $f = 2.0$ the population was definitely extinguished. The equilibrium data for $f = 0.0$ to 1.3 were fit to the generalized stock production model with PRODFIT to illustrate the obtainable degree of correspondence. The generalized stock production model very closely approximates the equilibrium values for the simulated pandalid shrimp population being slightly low in the range of $f = 0.7$ to 1.1 and slightly high beyond $f = 1.1$ (Figure 2). The estimated parameters are also very close (Table 1).

TABLE 1.—Empirical management implications for the simulated pandalid shrimp population and those estimated for the generalized stock production model with PRODFIT.

Method	Y_{max}	U_{max}	f_{opt}	q	m
Empirical	5.60	17.96	1.02	1.0	—
PRODFIT	5.56	17.91	1.11	—	0.604

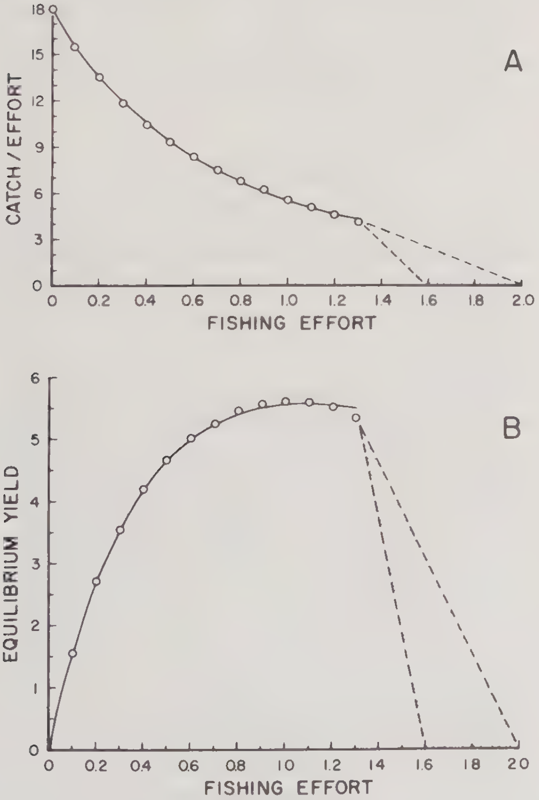

FIGURE 2.—Fit of the generalized stock production model (line) to simulated equilibrium values (circles) of (A) catch per unit effort and (B) yield by computer program PRODFIT. Shaded areas represent nonequilibrium.

The problem which confronts a fishery scientist is to estimate the parameters of Table 1, hence the equilibrium relationship of Figure 2, from catch and fishing effort data representing transitional rather than equilibrium states. To illustrate the efficacy of the equilibrium approximation approach and to provide a comparison between the two fishing effort averaging methods, a 12-yr fishing effort history was selected which approximates the rapid expansion of fishing for *Pandalus borealis* in Ugak Bay, Alaska. Exploiting the simulated shrimp population with the fishing effort history produced the catch and catch per unit effort history in Figure 3. Two comparisons were made, the first using the deterministic data shown in Figure 3 and the second introducing some random error.

Deterministic Comparison

The appropriate averaging time, k, for the weighted average method is four since the fishable part of the simulated shrimp population consists of four significant year classes. The appropriate averaging time, T, for the unweighted average method is 2 since the average duration of the fishable phase is 2 yr. The results of fitting the

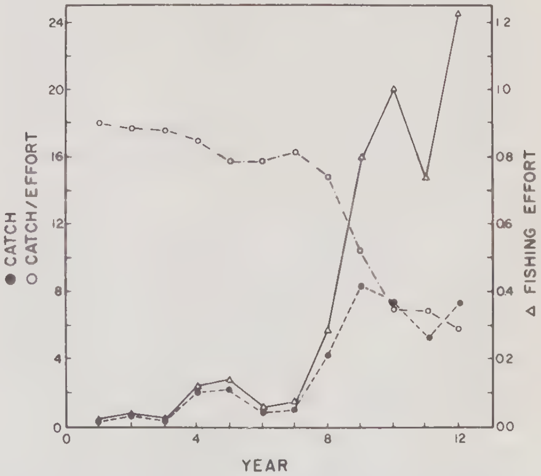

FIGURE 3.—Catch (dots) and catch per unit effort (circles) calculated with a fishing effort history (triangles) from the simulated pandalid shrimp population.

12-yr catch and fishing effort history by both methods for a range of averaging times are given in Table 2. Examination of the appropriate row for each method in Table 2 clearly reveals that for this example the superior estimates were produced by the weighted average method. In fact, the maximum error among the weighted average estimates of m, $Y_{\max}$, and $U_{\max}$ (the parameters used in searching for the least-squares solution) at $k = 4$ is only 1%.

The effect of different averaging times on the estimates of the parameters m, $Y_{\max}$, and $U_{\max}$ is the same for both effort averaging methods. By increasing the averaging time, the estimates of m and $Y_{\max}$ decrease and the estimate of $U_{\max}$ increases. The residual sum of squares is minimum at the appropriate averaging time for the weighted method (i.e. at $k = 4$). For the unweighted method, however, the minimum residual sum of squares is at 1 yr greater than the appropriate criterion.

Another way of comparing the weighted and unweighted averaging methods is to examine how well they estimated the equilibrium fishing effort. The equilibrium fishing effort was computed for each year's observed catch per unit effort (Figure 3), using the production model fitted to the equilibrium data (Table 1) for interpolation. The estimated equilibrium fishing effort by the weighted average method was closest in 10 of the 12 yr and had a mean absolute error of less than one-third of the unweighted method (Table 3).

Estimates of the catchability coefficient, q, by the integral method, Equation (22), —geometric and arithmetic means—and the difference method, Equation (18), for the weighted ($k = 4$) and unweighted ($T = 2$) fishing effort averaging techniques are given in Table 4. The best estimator within either effort averaging method was the integral method's geometric mean, with the weighted average fishing effort method being closest to the assumed value, 1.0.

TABLE 2.—Empirical and estimated parameters for the simulated pandalid shrimp catch history using the equilibrium approximation approach and two methods of averaging fishing effort.

Method	Averaging time (k or T)	$\hat{m}$	$\hat{Y}_{\max}$	$\hat{U}_{\max}$	$^1\hat{q}$	Mean squared error
Empirical	—	^{2}0.60	5.60	17.96	1.00	—
Weighted	1	1.16	7.26	17.63	0.42	1.3830
average	2	1.35	6.48	17.61	0.62	0.3293
fishing	3	0.86	6.02	17.82	0.88	0.0686
effort[3]	^{4}4	0.60	5.67	17.97	0.87	0.0500
	5	0.53	5.21	18.01	0.75	0.0913
	6	0.51	4.76	18.02	0.62	0.1236
Unweighted	1	1.16	7.26	17.63	0.42	1.3830
average	^{4}2	1.09	6.17	17.69	0.70	0.1323
fishing	3	0.35	6.10	18.07	1.12	0.0529
effort[5]	4	0.28	5.36	18.14	0.69	0.2797

[1] Integral method, geometric mean.
[2] Estimated, Table 1.
[3] Equation (9); Program PRODFIT, unweighted estimates option.
[4] Appropriate averaging time.
[5] Equation (7); Program PRODFIT, unweighted estimates option.

TABLE 3.—Comparison of two estimates of equilibrium fishing effort for the simulated pandalid shrimp population catch history.

Year	Equilibrium effort[3]	Weighted average estimate[1]		Unweighted average estimate[2]	
		Effort	Error	Effort	Error
1	0.0000	0.0000	−0.0000	0.0000	−0.0000
2	0.0072	0.0116	−0.0044	0.0145	−0.0073
3	0.0109	0.0099	0.0010	0.0160	−0.0051
4	0.0412	0.0515	−0.0103	0.0575	−0.0163
5	0.0897	0.0891	0.0006	0.1210	−0.0313
6	0.0896	0.0801	0.0095	0.0880	0.0016
7	0.0692	0.0726	−0.0034	0.0500	0.0192
8	0.1327	0.1516	−0.0189	0.1685	−0.0358
9	0.4031	0.4195	−0.0164	0.5405	−0.1374
10	0.7461	0.7094	0.0367	0.9090	−0.1629
11	0.7800	0.7887	−0.0087	0.8785	−0.0985
12	0.9356	1.0025	−0.0669	0.9905	−0.0549
Mean absolute error			0.0147		0.0475

[1] Equation (9); $k = 4$.
[2] Equation (7); $T = 2$.
[3] Calculated from Table 1 parameters.

Stochastic Comparison

In the deterministic comparison, the catch and fishing effort data were known precisely, the catch per unit effort was always exactly proportional to the average population size, and the population did not fluctuate. However, the stochastic nature of population processes, temporal and spatial changes in the availability and vulnerability of the population to fishing, and the use of sample data to represent an entire fishery all introduce considerable variability in real catch and effort data. Under the assumption that the component sources of variability are independent and random variables with constant expected values and variances, an approximation of the overall variability

TABLE 4.—Estimates of the catchability coefficient, q, by three methods for the weighted and unweighted fishing effort averaging techniques. Actual value of q is 1.0.

Effort averaging method	Integral method[1]		Difference method[2]
	Geometric mean	Arithmetic mean	
Weighted $\bar{f}$[3]	0.8684	1.1949	1.3283
Unweighted $\bar{f}$[4]	0.6978	1.3558	2.6606

[1] Equation (22).
[2] Equation (18).
[3] Equation (9); $k = 4$.
[4] Equation (7); $T = 2$.

structure is the multiplicative error model (Fox 1971)

$$C_i = C_i^* \cdot \epsilon_i \tag{28}$$

where C_i is the observed catch in year i, C_i^* is the expected catch, and ϵ_i is a random variable with an expected value of 1 and standard deviation σ. In practice, however, the ϵ_i are usually correlated because some (or all) of the component sources of variability do not meet the assumptions.

An ideal (i.e., in the sense that the ϵ_i are independent and random) error structure was chosen to illustrate the estimation ability of the two equilibrium approximation methods, because the "true" error structure of any given population and fishery is unique and largely unknown. Five independent sets of 12 pseudorandom, normally distributed variables, δ, as with an expectation of zero and a standard deviation of 0.1 were produced with the Library Subroutine RAND (University of Washington Computer Center, Seattle). The sets of δ's were used to produce five stochastic catch data sets from the deterministic catch history (Figure 3) and Equation (28), with ϵ_i defined as $1 + \delta_i$.

The results of fitting the five replicate sets of catch and effort data by the weighted (Equation 9) and unweighted (Equation 7) averaging methods are given in Table 5. The effects of even moderate variability on the parameter estimates for both averaging methods are apparent. On the average, two (m and $Y_{\max}$) of the three determining parameters (m, $Y_{\max}$, and $U_{\max}$) are closer to the empirical values for the weighted effort averaging method. The important observation, however, is that all the unweighted estimates of $Y_{\max}$ fall above the empirical value and that the average over the five replicates is significantly different from the empirical value with probability greater than 0.999.

Plots of the empirical equilibrium yields and those determined from the generalized stock production model parameters estimated by the weighted average method are compared in Figure 4. Equilibrium yield, for the most part, is estimated reasonably well in each replicate for the range of estimated "equilibrium" fishing effort, 0.0 to 1.0 (Table 3). The exception is replicate 4 where the empirical equilibrium yield is substantially underestimated above f = 0.8. Beyond the range of data, f = 1.0 to 1.3, the equilibrium yield is estimated reasonably well on the average, but not individually. None of the fitted models, of

TABLE 5.—Empirical and estimated parameters for the five replicated stochastic catch histories using the equilibrium approximation approach and two methods of averaging fishing effort.

Method	Replicate	$\hat{m}$	$\hat{Y}_{\max}$	$\hat{U}_{\max}$	$^1\hat{q}$	Mean squared error
Empirical	—	[2]0.60	5.60	17.96	1.00	[3]0.0100
Weighted average fishing effort[4]	1	1.03	5.80	17.49	0.53	0.0136
	2	0.00	8.65	18.99	1.56	0.0107
	3	0.60	5.73	17.97	0.87	0.0083
	4	1.04	5.07	18.68	0.95	0.0047
	5	0.24	6.68	18.40	1.13	0.0145
	Mean	0.58	6.39	18.30	1.01	0.0104
	[5]$SE_{\bar{x}}$	0.21	0.62	0.26	0.17	0.0018
Unweighted average fishing effort[6]	1	2.19	6.70	17.10	0.65	0.0110
	2	0.44	6.64	18.62	1.74	0.0130
	3	1.41	6.27	17.54	0.90	0.0100
	4	2.17	6.45	18.06	0.89	0.0095
	5	1.34	6.26	17.79	0.95	0.0117
	Mean	1.51	6.46	17.82	1.03	0.0110
	$SE_{\bar{x}}$	0.32	0.09	0.25	0.19	0.0006

[1] Integral method, geometric mean.
[2] Estimate, Table 1.
[3] Assumed value.
[4] Equation (9); k = 4; Program PRODFIT, weighted estimates option.
[5] Standard error of the mean.
[6] Equation (7); T = 2; Program PRODFIT, weighted estimates option.

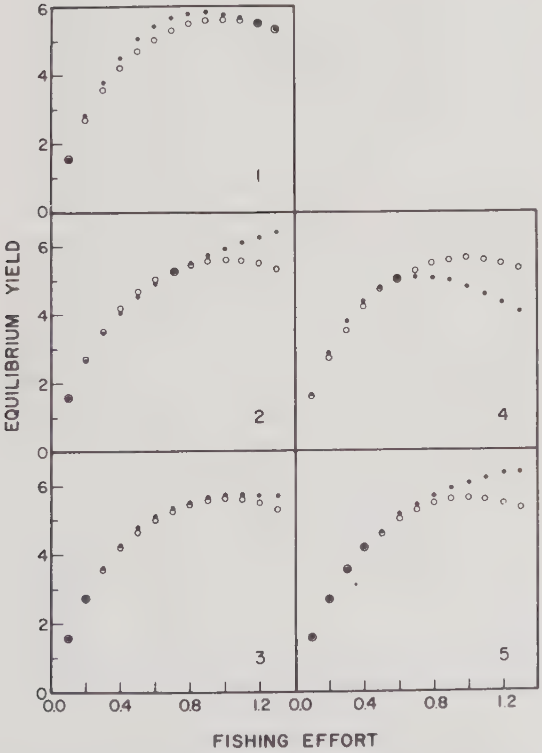

FIGURE 4.—Results (dots) of five stochastic simulated catch trials for the equilibrium approximation approach to fitting the generalized stock production model with the weighted averaging method. Circles are the true values.

course, reveal that there is no equilibrium yield in the range of $f = 1.6$ to 2.0 for the simulated shrimp population (Figure 2).

Table 6 provides a comparison of the catchability coefficient estimates by three techniques for each fishing effort averaging method. Clearly the best estimates were produced by the geometric mean for the integral method, with the mean estimate by the weighted average fishing effort procedure being slightly better than that of the unweighted average procedure.

TABLE 6.—Estimates of the catchability coefficient, q, from the five replicated stochastic catch histories by three methods for the weighted and unweighted fishing effort averaging procedures. Actual value of q is 1.0.

Effort averaging method	Estimation method	Mean $\hat{q}$	Range of $\hat{q}$
Weighted $\bar{f}$[1]	Integral method[2]		
	Geometric mean	1.008	0.53-1.56
	Arithmetic mean	1.660	1.27-2.41
	Difference method[3]	1.503	1.35-1.77
Unweighted $\bar{f}$[4]	Integral method		
	Geometric mean	1.028	0.65-1.74
	Arithmetic mean	1.546	1.12-2.11
	Difference method	4.459	2.22-10.47

[1] Equation (9); $k = 4$.
[2] Equation (22)
[3] Equation (18).
[4] Equation (7); $T = 2$.

COMPARATIVE EXAMPLES OF THE EQUILIBRIUM APPROXIMATION AND TRANSITION PREDICTION APPROACHES

Computer program GENPROD (Pella and Tomlinson 1969) was employed to fit the deterministic and stochastic catch and effort histories of the simulated shrimp to compare the results of the transition prediction and equilibrium approximation approaches. The reader is cautioned, as in the previous section, that these results are largely illustrative and should not be misconstrued as being valid for all cases in which a production model may be employed.

Deterministic Comparison

The comparison of equilibrium parameters in Table 7 reveals that the equilibrium approximation approach provided estimates that were closer to all the empirical values except m, where the two approaches estimated the same value as the empirical equilibrium fit. GENPROD estimated parameters which predicted the simulated catch history (Figure 3) extremely well—the largest error was only 0.05, the sum of squared errors was 0.00659, and the R statistic, a measure of improvement in the fit over simply using the mean catch as a predictor (Pella and Tomlinson 1969), was 0.99994. Utilizing the empirical equilibrium parameters in the generalized production model, however, resulted in a poorer, but still good, prediction of the transition state catches—the maximum error was 0.50, the sum of squared errors was 0.48515, and the R statistic was 0.99544. Apparently due to failure of the assumptions regarding population lag and age structure shifts or problems with precision in the numerical integration, the accuracy of some equilibrium parameter estimates by the transition prediction approach were sacrificed in order to reduce the sum of squared errors by nearly 99%.

Stochastic Comparison

The results of fitting the five replicate stochastic catch histories by the equilibrium approximation and transition prediction approaches are given in Table 8. Of the four common parameters (m, $Y_{\max}$, $U_{\max}$, and q), the equilibrium approximation approach estimates were closer to the empirical values of m, $Y_{\max}$, and q, both on the average and for most of the replicates. The transition prediction approach estimates were closer, on the average, to the empirical value for $U_{\max}$. The transition prediction approach provided one extremely poor estimate of q (replicate 3) and all replicate estimates are above the empirical value—the latter phenomenon could be related to the accuracy of the numerical integration scheme in GENPROD (Fox 1971). The additional parameter required by GENPROD, the ratio of the initial to unexploited population size ($P_0/P_{\max}$), was estimated very well.

There is considerable variability in the estimates of the most frequently desired parameter, $Y_{\max}$, by either approach (Table 8) in spite of assuming an ideal error structure (independent,

TABLE 7.—Empirical and estimated parameters for the simulated pandalid shrimp catch history using the equilibrium approximation and transition prediction approaches.

Approach	$\hat{m}$	$\hat{Y}_{\max}$	$\hat{U}_{\max}$	$\hat{q}$	$\widehat{P_0/P_{\max}}$
Empirical	[1]0.60	5.60	17.96	1.00	1.00
Equilibrium approximation[2]	0.60	5.67	17.97	0.87	—
Transition prediction[3]	0.60	5.92	17.69	1.32	1.16

[1] Estimated, Table 1.
[2] Program PRODFIT, $k = 4$, unweighted estimates option.
[3] Program GENPROD, KK = 3, DEL = 3, unweighted estimates.

TABLE 8.—Empirical and estimated parameters for the five replicated stochastic catch histories using the equilibrium approximation and transition prediction approaches.

Method	Replicate	$\hat{m}$	$\hat{Y}_{max}$	$\hat{U}_{max}$	$\hat{q}$	$P_0/\overline{P}_{max}$	Mean squared error
Empirical	—	[1]0.60	5.60	17.96	1.00	1.000	[2]0.0100
Equilibrium approximation approach[3]	1	1.03	5.80	17.49	0.53	—	0.0136
	2	0.00	8.65	18.99	1.56	—	0.0107
	3	0.60	5.73	17.97	0.87	—	0.0083
	4	1.04	5.07	18.68	0.95	—	0.0047
	5	0.24	6.68	18.40	1.13	—	0.0145
	Mean	0.58	6.39	18.30	1.01	—	0.0104
	[4]$SE_{\bar{x}}$	0.21	0.62	0.26	0.17	—	0.0018
Transition prediction approach[5]	1	1.7	5.81	17.72	1.34	0.738	0.0105
	2	0.0	9.09	18.15	1.18	1.095	0.0131
	3	2.1	6.69	17.29	3.97	1.211	0.0086
	4	1.7	5.26	17.83	1.40	1.313	0.0053
	5	0.0	9.34	19.21	1.52	0.797	0.0126
	Mean	1.10	7.24	18.04	1.88	1.031	0.0100
	$SE_{\bar{x}}$	0.45	0.84	0.32	0.52	0.113	0.0014

[1] Estimated, Table 1.

[2] Assumed value.

[3] Program PRODFIT; $k = 4$, weighted estimates option.

[4] Standard error of the mean.

[5] Program GENPROD; KK = 3, DEL = 3, weighted estimates. The program was modified slightly from the version of Pella and Tomlinson (1969) by replacing f_{opt} with Y_{max} as one of the determining parameters to allow fitting the case where $\hat{m} \to 0$ (i.e. $\hat{f}_{opt} = \infty$ at $m = 0$). Identical solutions were obtained for the remaining three cases with either version

random and with constant expectation and variance), the observed catch being within 20% of the expected catch with probability 0.95, and the fishing effort being known without error. The maximum error for the equilibrium approximation approach was +54% (replicate 2) and for the transition prediction approach was +67% (replicate 5). The problem with these maximum errors (as well as an additional replicate of the transition prediction approach) was estimating m as 0.0, where Y_{max} occurs at infinite fishing effort. It is not unreasonable, however, to obtain $\hat{m} = 0.0$ since the data series is so short and the best value for m is about 0.60. Considering these results and the true relationship between yield and effort (Figure 2) it would be prudent to adopt an alternative m estimation strategy for short data series.

Alternative strategies which could be adopted for short data series are 1) to consistently assume one of the special cases of the generalized stock production model, either the logistic form ($m = 2$) or the Gompertz form ($m \to 1$), or 2) fit both special cases and select the one with the least sum of squared errors. Table 9 presents the parameters estimated by the two approaches through fixing the value for m at 1 (actually 1.001) and 2. For comparative purposes, the results of these alternative strategies are summarized in Table 10. Fixing m at 1 or 2 resulted in average estimates of Y_{max} nearer the empirical value with less variability than obtained by allowing m to be freely estimated for both the equilibrium approximation and transition prediction approaches. The empirical value of m is 0.6; hence assuming $m \to 1$ produced estimates nearer the empirical value of Y_{max} than assuming $m = 2$. For any given data set, however, one could not determine a priori which value of m to assume. The strategy of fitting both $m \to 1$ and $m = 2$ and then selecting that which provided the least-squares parameter estimates worked very well in comparison with freely estimating m under three criteria: 1) more accurate average estimate, 2) smaller average percentage error, and 3) smaller maximum overestimate. Comparing the equilibrium approximation and transition prediction approaches with the same three criteria reveals that the equilibrium approximation approach was superior [1) 0.5% vs. 5.2%, 2) 3.6% vs. 8.5%, and 3) 3.6% vs. 18.4%)].

DISCUSSION

The simple, illustrative calculations on the simulated pandalid shrimp population, of course, did not determine which of the approaches was better for general use in fitting the generalized stock production model. However, some additional guidance can be gained through examining some of their relative weaknesses with regard to the number of data points and the number of parameters they require.

The moving average of fishing effort in the equilibrium approximation approach results in the exclusion of points at the beginning of the data

TABLE 9.—Estimated parameters for the five replicated stochastic catch histories using the equilibrium approximation and transition prediction approaches for fixed estimates of *m*.

Method	m	Replicate	$\hat{Y}_{max}$	$\hat{U}_{max}$	$\hat{q}$	$\widehat{P_0/P_{max}}$	Mean squared error
Equilibrium approximation approach[1]	1	1	5.80	17.51	0.54	—	0.0136
		2	5.63	17.99	1.36	—	0.0155
		3	5.56	17.66	0.99	—	0.0087
		4	5.05	18.72	0.92	—	0.0048
		5	5.78	17.73	0.95	—	0.0166
		Mean	5.57	17.92	0.96	—	0.0118
	2	1	6.27	16.73	0.29	—	0.0182
		2	6.27	17.17	1.14	—	0.0267
		3	6.06	16.92	0.88	—	0.0139
		4	5.86	17.65	0.77	—	0.0115
		5	6.35	16.94	1.19	—	0.0260
		Mean	6.16	17.08	0.85	—	0.0193
Transition prediction approach[2]	1	1	5.44	18.18	1.10	0.778	0.0107
		2	6.00	18.16	1.79	1.014	0.0170
		3	6.39	17.81	2.97	1.058	0.0096
		4	4.66	18.08	1.07	1.162	0.0058
		5	6.10	18.40	1.87	0.715	0.0142
		Mean	5.72	18.13	1.76	0.945	0.0115
	2	1	5.95	17.61	1.38	0.720	0.0107
		2	6.47	17.83	2.40	0.962	0.0201
		3	6.63	17.37	3.62	1.210	0.0084
		4	5.30	17.73	1.35	1.361	0.0051
		5	6.51	17.89	2.29	0.604	0.0165
		Mean	6.17	17.69	2.21	0.971	0.0122

[1] Program PRODFIT; $k = 4$, weighted estimates option.
[2] Program GENPROD; KK = 3, DEL = 5, weighted estimates.

TABLE 10.—Summary of Y_{max} estimates by alternative strategies with the equilibrium approximation and transition prediction approaches for five replicated stochastic catch histories. Empirical value of Y_{max} is 5.60.

Method/strategy	$\hat{Y}_{max}$ Mean	Standard error of mean	Average percentage error	Range
Equilibrium approximation approach[1]				
1. Estimate m	6.39	0.62	17.8	5.07-8.65
2. Assume $m \rightarrow 1$	5.57	0.14	3.6	5.05-5.80
3. Assume $m = 2$	6.16	0.09	10.0	5.86-6.35
4. Least-squares, $m = 1$ or 2	5.57	0.14	3.6	5.05-5.80
Transition prediction approach[2]				
1. Estimate m	7.24	0.84	31.7	5.26-9.34
2. Assume $m \rightarrow 1$	5.72	0.31	10.0	4.66-6.39
3. Assume $m = 2$	6.17	0.25	12.4	5.30-6.63
4. Least-squares, $m = 1$ or 2	5.89	0.24	8.5	5.30-6.63

[1] Program PRODFIT.
[2] Program GENPROD.

set unless either there was no fishing prior to the first record of the set or some information is available on the approximate level of catch and effort. One should check carefully to ensure that critical points (those being the only points at high, low, or intermediate levels of fishing) are not excluded or that the fitted model does not deviate greatly from where they might reasonably be expected to lie. If fishing effort was reasonably constant or negligible prior to the first record, dummy data of length $k - 1$ can be employed to allow use of the first few data points. Also, since the average fishable duration, T, is less than the number of significant fishable year classes, k, the unweighted averaging method will result in fewer data being excluded In any case, the sensitivity of the parameter estimates to alternative averaging times should be explored.

No data points are excluded with the transition prediction approach, a positive factor which should be considered even if one is satisfied with the parameter estimates obtained with the equilibrium approximation approach. On the other hand, the transition prediction approach utilizes five parameters while the equilibrium approximation approach utilizes only three, so that with few significant year classes in the fishable population there is little difference between the required number of data points. For example, the transition prediction approach statistically requires six points, while the equilibrium approximation approach with four significant year classes will require, in general, seven points. With a large number of significant year classes in the fishable population or a relatively high age at first capture, however, the major concern for either approach is the likelihood of failure of the transition state population assumptions.

The results summarized in Table 7 illustrate a general shortcoming in simultaneously estimating a large number of parameters, i.e. large deviations from model can be statistically reduced in a least-squares estimation procedure at the expense of the accuracy of certain "desired" parameters. The transition prediction approach, fitting a "free-form" type of curve with five parameters, is relatively more susceptible than the equilibrium approximation approach which fits a monotonically decreasing curve with only three parameters. On the other hand, estimates from the equilibrium approximation approach can be very sensitive to the placement of one data point in certain cases (e.g., a data point at an intermediate level of fishing with clusters of points at both low and high levels of fishing).

Utilizing the production model approach for assessing the effects of exploitation presents significant problems in addition to choice of the parameter estimation procedure or the length of the data series. These additional problems are 1) maintaining a constant catchability coefficient throughout the data series, 2) assessing the effects of changes in the constitution of the fishery, and 3) assessing the effects of time lags in population production processes.

The basic components of the overall effective catchability coefficient are 1) the relative efficiency of various types and classes of fishing gear and 2) the manner in which the gear is employed relative to the availability and vulnerability of the population, and its subunits, to capture. Heterogeneity in the efficiency of various gear classes, or vessels, within a fishing season can be alleviated by adjusting for their estimated relative fishing powers—currently the best method for estimating fishing power is by analysis of variance with the computer program FPOW (Berude and Abramson 1972). The major problem remaining, however, is adjusting for among-year changes in efficiency of the standard gear. Rothschild (1970) discussed and provided examples of problems associated with changes in the catchability coefficient related to areal deployment of the fishing gear. The expansion of fishing across a gradient of population density will increase or decrease the effective catchability coefficient depending on the direction of the density gradient and fishing expansion. Year-to-year shifts in the population location and density relative to the fishing effort deployment also could likewise create trends in the catchability coefficient. Age-specific differences in the catchability would cause shifting of the overall effective catchability coefficient with changes in fishing effort. For example, if the catchability of fish declined with age, then the overall effective catchability of the fishable population would increase with increasing fishing effort since the relative proportion of younger age groups would most likely increase.

Alterations in the constitution of the fishery probably are the most difficult problems to overcome satisfactorily. Expansion of the fishery across several stocks, either independent or with some mixing, can result in rather large shifts in the productivity estimates (Joseph 1970; Inter-American Tropical Tuna Commission 1972). Changes in the relative levels of fishing effort exerted by different gear types which exploit different age groups of the population, either voluntarily or through a change in minimum size limit regulations, can similarly have significant impact on the shape of the production model curve (Lenarz et al. 1974). The latter problem identifies a major shortcoming of the production model approach; i.e., the impact on total yield by altering the selectivity of fishing gear can not be assessed a priori without considerable additional information.

The effects of time lags in population production processes (e.g., reproduction, growth, and mortality, both density-independent and density-dependent) can result in either overestimation or underestimation of the population productivity, or in population cycling which may never result in reaching an equilibrium state (Wangersky and Cunningham 1957; Walter 1973).

In summary, both the equilibrium approximation and the transition prediction fitting methods are useful, one or the other more so under conditions outlined above. Application of the production model to catch and fishing effort data is relatively simple, the primary virtue of the approach. The interpretation of the results and the formulation of advice for managing the resource, however, can be extraordinarily complicated by a variety of factors. Therefore, the proper perspective of production model analysis is that it is little more than a regression model, yet very useful for making "first estimate" projections of the relationship between the level of exploitation and expected equilibrium yield.

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NOTES

A PRELIMINARY LIST OF FISHES COLLECTED FROM RICHARDSON BAY, CALIFORNIA 1972–1973

From June 1972 to July 1973 sampling of fish eggs and larval, juvenile and adult fishes was conducted by Tiburon Fisheries Laboratory (National Marine Fisheries Service, NOAA) in Richardson Bay, a part of the San Francisco Bay system (Fig. 1). The sampling was part of a pilot program to lead toward a more extensive baseline study of fishery resources and their ecological relationships within and dependence upon San Francisco Bay.

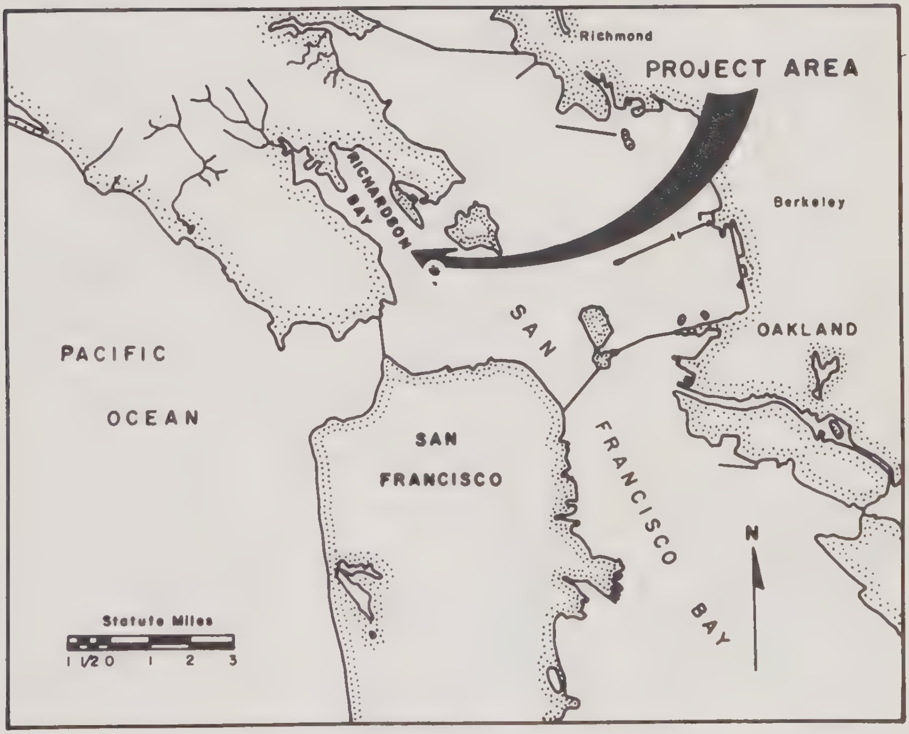

FIGURE 1. Location Map.

Sampling for adult and juvenile fishes was conducted with gill nets and trawls at 9 randomly selected stations each month with the exception of October 1972. The gill nets used were 6 ft in depth by 100 ft long and made of monofilament nylon. Each net was constructed from different panels laced together. The mesh sizes of these panels were randomly selected from 1, $1\frac{1}{2}$, 2, $2\frac{1}{2}$, 3, 4 and 6 inch stretched mesh, each size being used twice in the four nets that we used. At each station selected, one net was fished for 2 hours at the surface. Often, in waters less than 6 ft deep, the nets covered the entire water column.

The trawl was a standard shrimp "try net" with head rope length

TABLE 1—**Fishes Collected From Richardson Bay, 1972–1973**

Scientific name	Common name	Eggs or larvae collected	Number of juveniles or adults captured
Mustelus henlei	Brown smoothhound		38
Triakis semifasciata	Leopard shark		42
Squalus acanthias	Spiny dogfish		1
Raja trachura	Roughtail skate		1
Myliobatis californica	Bat ray		4
Acipenser medirostris	Green sturgeon		3
Alosa sapidissima	American shad		1
Clupea harengus pallasi	Pacific herring	x	22
Dorosoma petenense	Threadfin shad		7
Engraulis mordax	Northern anchovy	x	9
Hypomesus pretiosus	Surf smelt		5
Porichthys notatus	Plainfin midshipman		16
Merluccius productus	Pacific hake	x	
Microgadus proximus	Pacific tomcod		34
Brosmophycis marginata	Red brotula	x	
Atherinops affinis	Topsmelt		265
Atherinopsis californiensis	Jacksmelt		351
Syngnathus griseolineatus	Bay pipefish	x	14
Morone saxatilis	Striped bass		72
Trachurus symmetricus	Jack mackerel	x	
Cynoscion nobilis	White seabass	x	
Genyonemus lineatus	White croaker		1
Cymatogaster aggregata	Shiner perch		1,716
Embiotoca jacksoni	Black perch		49
Hyperprosopon argenteum	Walleye surfperch		23
Hypsurus caryi	Rainbow seaperch		9
Micrometrus minimus	Dwarf perch		133
Phanerodon furcatus	White seaperch		1,353
Rhacochilus toxotes	Rubberlip seaperch		8
Rhacochilus vacca	Pile perch		93
Neoclinus uninotatus	Onespot fringehead		1
Clevelandia ios	Arrow goby		1
Lepidogobius lepidus	Bay goby		3
Peprilus simillimus	Pacific pompano		1
Sebastes auriculatus	Brown rockfish		9
Hexagrammos decagrammus	Kelp greenling		1
Ophiodon elongatus	Lingcod		16
Enophrys bison	Buffalo sculpin		2
Leptocottus armatus	Pacific staghorn sculpin	x	176
Oligocottus maculosus	Tidepool sculpin	x	
Scorpaenichthys marmoratus	Cabezon		1
Citharichthys sordidus	Pacific sanddab	x	7
Citharichthys stigmaeus	Speckled sanddab		165
Paralichthys californicus	California halibut	x	
Hypsopsetta guttulata	Diamond turbot	x	3
Parophrys vetulus	English sole		674
Platichthys stellatus	Starry flounder	x	70
Symphurus atricauda	California tonguefish	x	

of 20 ft and foot rope of 23½ ft. Otter boards measured 1 ft by 2 ft and were hung from 10 ft bridles. Mesh size in the main body of the net was 1⅜ inch stretched mesh with 1 inch stretched mesh in the cod end. The trawl was always fished on the bottom. At each station, one 3-minute tow was made at a speed of 3.5 knots.

Ichthyoplankton was sampled with surface plankton tows using a half-meter net and on 24-hr monitoring stations using an anchored channel net (Lewis, *et al.* 1970). Three-minute tows were made in replicates of two at 15 randomly selected stations each 6 weeks. Each 12 weeks, 24-hr monitoring was conducted at 2 fixed stations, one in the main ship channel off the Corps of Engineers dock in Sausalito, the other inside Cone Rock, near the mouth of Richardson Bay. The direction of the channel net was reversed at each tidal change.

All of the juvenile and adult fish sampling and surface plankton tows were conducted during daylight hours.

This preliminary list (Table 1.) of fishes collected and their relative abundance in the catch is published here for the possible interest of other workers in the shallow areas of San Francisco Bay. Two species in this list have not to my knowledge been reported previously from San Francisco Bay: roughtail skate (*Raja trachura*) and white seabass (*Cynoscion nobilis*). Unaware of its rarity, I identified the male roughtail skate in the field, using Miller and Lea's (1972) guide and returned it to the water. It was caught in the trawl on May 31, 1973. The white seabass larva was collected and identified by Maxwell Eldridge (Tiburon Fisheries Laboratory) in June 1972. Identification was verified by Elbert H. Ahlstrom. The specimen is preserved in the reference collection at Tiburon Fisheries Laboratory.

I do not presume that the list is completely representative of fishes found in Richardson Bay. Shortcomings of gear and sampling methods normally preclude this possibility. Much of the plankton material is still being worked up. We expect additional species will show up in these collections. More detailed publications will follow a more intensive examination of our data and collected materials.

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NOTES

DISTRIBUTION OF MELANIN IN THE COLOR PATTERN OF *DELPHINUS DELPHIS* (CETACEA; DELPHINIDAE)

Previous studies of cetacean pigmentation have been concerned with the description of color patterns and the possibilities for their evolutionary production and their adaptive significance. Mitchell (1970) identified four basic color patterns among the Delphinidae: saddled, as exemplified by some species of *Stenella*; spotted, as seen in *Stenella plagiodon*; striped, as seen in *Stenella coeruleoalba*; and crisscross, as seen in *Delphinus delphis*. Naming the crisscross pattern as the most complex, Mitchell used it to establish a terminology for elements of the color patterns. One of his conclusions concerning the evolutionary development of the patterns was that the saddled pattern is most primitive, since it is closest to generalized countershading and because one may hypothetically derive the other three patterns from it by addition of certain features, emphasis of some features, and de-emphasis of others.

Perrin (1972) compared the color pattern of a partially albinistic whitebelly spinner (*S. longirostris*) with that of a normally pigmented individual and showed that the normal color pattern may be described in terms of two independently produced but interacting pigmentation systems or components, only one of which had developed in the partially albinistic individual. Using the two-component approach, he analyzed the color patterns of other delphinids, including *Delphinus* spp., and proposed pattern homologies among the species. He suggested that the more generalized of the two pigmentation systems involves the cape (terminology of Perrin 1970) and its accessory stripes, eye and gape marks, and dorsal fin and fluke colorations. This is overlaid by a second component system that he named the "dorsal overlay system." He proposed that partial overlapping of the two produces the four-part crisscross pattern in *Delphinus*.

If two discrete interacting pigmentation systems are involved in the color pattern of *Delphinus*, that fact should be evidenced in the microstructure of the skin. Previous histological study of *Delphinus* skin provides only a description of the general microscopic anatomy. Stiglbauer (1913) described the microstructure of the skin of *Delphinus delphis* in great detail, including the existence of large dermal papillae and epidermal pegs with granular inclusions of pigment that he identified as melanin. His sample, however, was from the back of a single animal, and he did not have the opportunity to compare the distributions of pigment in different parts of the color pattern. Sokolov (1962) commented very briefly on the pigmentation of two specimens of *Delphinus*, stating that the epidermis on the back and below the dorsal fin was moderately pigmented, on the side of one animal was lightly pigmented, and along the side of the other animal and on the bellies of both was unpigmented. This paper reports the results of comparative microscopic examination of skin samples taken from various areas of the color pattern.

Materials and Methods

Skin samples, each about 5 cm square, were taken from various areas of the bodies of two animals as shown in Figure 1. The porpoise were collected at San Diego, Calif. One animal (field no. WFP 125, adult female, 176 cm, 61 kg) had been frozen for several months before dissection, and the other (WFP 221, adult male, 185 cm, 83 kg, Figure 2) was sampled about 1 h after death.

One centimeter-square specimens were fixed in 10% Formalin,[1] and imbedded in paraffin. Sections were cut 8 μm thick and stained with Schmorl's ferricyanide for malinin. This method stains melanins a dark blue or blue-green, while other epidermal and dermal tissue is stained light green.

The prepared sections were examined under a light microscope. Pigment densities were scored at 125 diameters magnification.

Results

General microscopic anatomy of the skin of *Delphinus* is simple when compared with that of terrestrial mammals and fits the description of cetacean skin given by Simpson and Gardner

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[1] Reference to trade names does not imply endorsement by the National Marine Fisheries Service, NOAA.

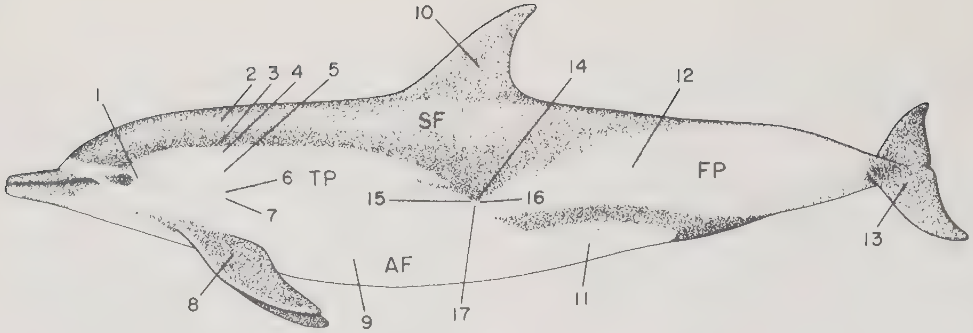

FIGURE 1.—Major pattern features (terminology of Mitchell 1970) and locations from which skin samples were taken: SF = spinal field (black), TP = thoracic patch (buff), FP = flank patch (gray), AF = abdominal field (white).

(1972). The epidermis generally lacks hair (a few hairs are present on the snout in early development but disappear before or shortly after birth), cuticular keratin, and accessory glands. Its thickness varies, being greatest in the ventral region and least on the flippers, dorsal fin, and flukes. The superficial layer of the epidermis, about 10 cells thick, shows considerable flattening of cells. The epidermis consists almost entirely of polyhedral prickle cells, many of which show clear, distended infranuclear cytoplasm. This clear cytoplasm at first appears as holes in the tissue when it is viewed in section, but upon closer examination one may identify the nucleoli inside the clear areas. The epidermis interlocks with the dermis by interdigitation of epidermal rete pegs and dermal papillae (Figure 3), and the dermis grades into the subcutaneous blubber layer. The dermis varies in thickness and density and is composed largely of collagen fibers. The dermal papillae contain blood vessels, blood cells, and other loosely organized connective tissue.

Melanin pigmentation is restricted to the epidermis and is consistently more concentrated at the edges of the epidermis than elsewhere. It is usually most concentrated around the bases of the dermal papillae (at the apices of the epidermal rete pegs) and extending in bands from the apices of the dermal papillae. The pigment has been classified here into three groups for purposes of quantification. "Diffuse" pigment appeared simply as an area which stained darker green than the background and in which pigment grains could not be discerned even at 1,250 diameters magnification. In addition to diffuse pigment, there were granules ranging from less than 0.1 μm to over 5 μm in diameter. Most were spherical or ellipsoid. Granules less than 5 μm in greatest diameter were termed "small grains." These seemed to be actually aggregations of even smaller granules. Those termed "large grains" were larger than 5 μm in diameter and were so dense as to appear as single entities even at high power. Diffuse pigment was characteristically situated peripheral to the nuclei of the prickle cells. This was particularly evident in the central areas of the epidermis. Pigment granules were in general most concentrated at the edges of the epidermis and appeared to extend toward the surface in diffuse bands. In the more lightly colored skin specimens these bands extended only from the apices of the dermal papillae, but in more densely pigmented skin they were more numerous and tended to blend together, resulting in uniform density of pigment throughout the epidermis.

The density of pigment was noted in three regions in each sample: around the bases and edges of the dermal papillae and in the bands described above (Table 1). The observations were each coded from 0 to 4 as follows: for diffuse pigment, 0 = none, 1 = very small amount, 2 = small amount, 3 = medium amount, 4 = large amount; for small grains, 0 = $<$ 1 grain per mm^2, 1 = 1-3 grains per mm^2, 2 = 4-7 grains per mm^2, 3 = 8-11 grains per mm^2, 4 = $>$ 12 grains per mm^2; for large grains, 0 = 0 grains per 4 mm^2, 1 = 1 grain per 4 mm^2, 2 = 2-3 grains per 4 mm^2, 3 = 3-6 grains per 4 mm^2, 4 = $>$ 6 grains per 4 mm^2. Skin samples which appeared white were completely unpigmented or showed very small amounts of diffuse and/or small grains. The buff color characteristic of the thoracic patch (terminology of Mitchell 1970) was associated with either equal prominence of diffuse and granular pigment or

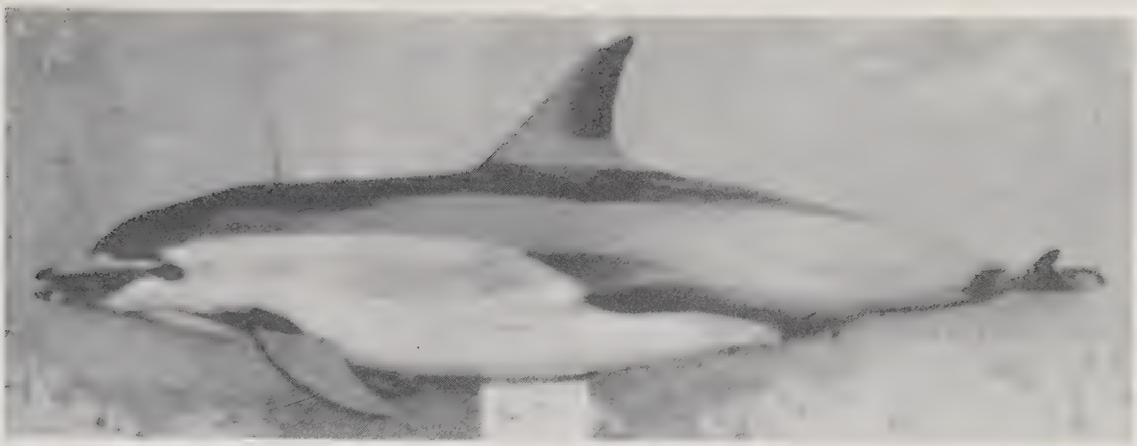

FIGURE 2.—*Delphinus delphis*: Specimen no. WFP 221.

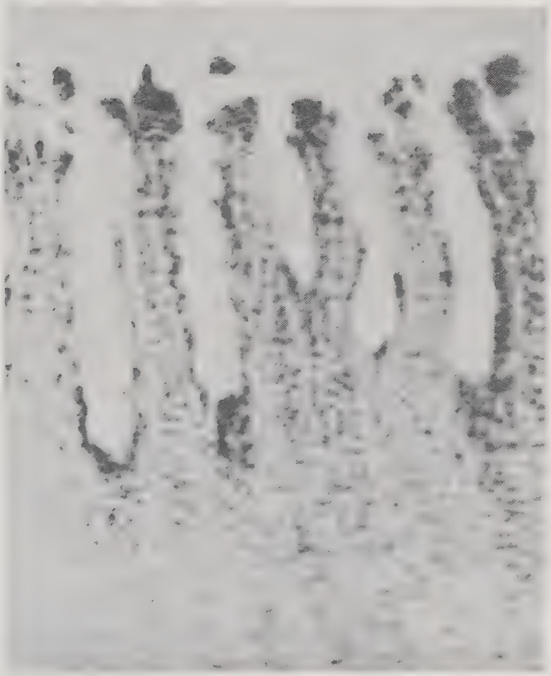

FIGURE 3.—Typical appearance of dermal-epidermal boundary of skin of *Delphinus delphis* (WFP 221 sample no. 10 in Table 1). Note concentration of pigment granules around bases of dermal papillae and in bands extending from ends of papillae. Magnification 1,250 diameters.

greater prominence of diffuse pigment. In gray samples from the flank patch, large grains were present, but the small grains were most prominent. Samples of black skin from flippers and flukes showed the highest densities of large grains, which were more prominent than the small grains.

The histological evidence (summarized in Table 2) supports the concept of interacting color pattern components. As indicated previously, the spinal field may be described as a result of the interaction of the pigmentation of the cape and the dorsal field. The buff colored thoracic patch (i.e., the cape) contains relatively high concentrations of diffuse pigment, while in the grey flank patch (i.e., the dorsal overlay) granular pigment is more prominent. The spinal field is characterized by a larger amount of diffuse pigment than is present in the flank patch, and a larger amount of granular pigment than is present in the thoracic patch. The high concentration of grains in the spinal field indicates a possible synergistic effect of the two component systems.

Perrin (1972) suggested that the flukes are pigmented only as part of the cape system. The skin of the flukes (sample no. 13) contained large amounts of all three types of pigment, indicating that pigmentation of the flukes involves both the cape system and the dorsal overlay system. The skin of the flipper (sample no. 8) also contained large amounts of all three types of pigment.

The major difference between samples taken from WFP 125 (female) and those taken from WFP 221 (male) was that the epidermis was thicker (0.75-1.70 mm as opposed to 0.50-0.95 mm) in the latter animal. Thus a lower density of pigment was required to produce the same color. Also, the samples taken from the buff-colored area of WFP 221 showed conspicuously less diffuse pigment.

TABLE 1.–Results of microscopic examination of pigment distribution in skin of two *Delphinus delphis*. Codes explained in text.

	Pigment density (coded)									
	Diffuse			Small grains			Large grains			
Sample no.	Bases	Edges	Bands	Bases	Edges	Bands	Bases	Edges	Bands	Color
WFP 125♀										
1	4	3	2	2	2	2	0	0	0	buff
2	4	3	1	4	4	2	4	3	3	black
3	3	3	1	4	3	2	4	3	2	black
4	3	3	2	2	2	1	1	0	0	buff
5	3	3	2	2	2	1	1	0	0	buff
6	3	3	1	2	2	1	0	0	0	buff
7	2	2	1	3	2	1	0	0	0	white
8	3	2	1	4	3	3	4	3	2	black
9	2	2	0	1	1	0	0	0	0	white
10	4	3	0	3	3	2	2	1	0	gray
11	2	2	1	1	1	0	0	0	0	white
12	2	1	0	3	2	2	1	0	0	gray
13	4	3	2	4	3	2	4	3	2	black
14	3	3	1	4	2	2	3	2	1	black
15	3	3	2	2	2	1	0	0	0	buff
16	2	2	0	3	2	2	1	0	0	gray
17	2	2	1	1	1	0	0	0	0	white
WFP 221♂										
1	2	2	1	2	2	1	0	0	0	buff
2	2	2	2	4	4	3	3	3	3	black
3	3	2	2	4	4	2	3	2	2	black
4	1	1	1	2	2	2	0	0	0	buff
5	2	2	1	2	2	1	0	0	0	buff
6	2	2	1	2	2	0	0	0	0	buff
7	0	0	0	1	1	0	0	0	0	white
8	3	2	1	4	4	3	3	2	2	black
9	0	0	0	0	0	0	0	0	0	white
10	3	2	1	3	3	2	2	2	2	gray
11	1	1	0	0	0	0	0	0	0	white
12	0	0	0	2	2	1	0	0	0	gray
13	3	2	2	4	4	2	3	2	2	black
14	3	3	2	3	3	2	3	2	2	black
15	2	2	1	1	1	0	0	0	0	buff
16	2	1	1	2	2	1	1	1	1	gray
17	1	1	0	1	1	0	0	0	0	white

TABLE 2.–Average pigment density values for four major features of the color pattern of *Delphinus delphis*. Coded values in Table 1 are averaged over bases, edges, and bands, over all relevant samples, and over both animals. Number of samples included for each animal is in parentheses.

	Pigment density		
Feature	Diffuse	Small grains	Large grains
Ventral field: white (4)	0.96	0.67	0
Thoracic patch: buff (5)	2.37	1.60	0.07
Flank patch: gray (2)	0.92	2.00	0.42
Spinal field: black (4)	2.46	3.08	2.67

Discussion

The color pattern of *Delphinus* evidently consists of two overlapping and interacting pigmentation components that differ mainly in the density and size of pigment particles. The pigment exhibits a continuum of grain size, with the very smallest particles being associated with a buff color. It seems likely that the diffuse pigment is also composed of particles too small for resolution with the light microscope. This evidence suggests that there may be a developmental progression in grain size from the unpigmented or truly white condition through buff and gray to black. This result is consistent with Mitchell's (1970) proposal of the "saddled" pattern as most primitive in recent cetaceans. Inhibition of pigment aggregation could result in the high concentration of diffuse pigment which is typical of buff regions in *Delphinus*. Fox (1953) and others have stated that there are different types of melanins, possibly characterized by different chemical compositions or structures, although none have been adequately described chemically, due to their insolubility and their general lack of adaptability to most physicochemical methods. From the previously described evidence it may be suggested that the type of malanin which produces the buff color is of a composition which does not allow its further polymerization, but may well favor its combination with a protein, as phaeomelanin, instead of aggregation into granules. One might also hypothesize control by dispersing or concentrating hormones, although this would be physiologically and developmentally more complex. In gray and black areas, aggregation of pigment seems to continue, and melanocytes migrate toward the surface from the base of the epidermis until diffuse pigment is largely replaced by granular pigment. The process is apparently stopped at some point, after which increase in thickness of the epidermis may result in a lower average density of pigment.

Acknowledgments

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Feeding Patterns among Tropical Reef Fishes

Understanding the way fishes respond to changing conditions during the day-night cycle provides insight into their feeding activities

Edmund S. Hobson

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Understanding the way fishes respond to changing conditions during the day-night cycle provides insight into their feeding activities

To eat and to avoid being eaten: the impact of these concerns on activity patterns and morphologies of tropical reef fishes has been the major thrust of my research over the past fifteen years. Here I draw together major elements of these studies, which have considered the fishes in their natural habitats at widely separated locations in the Pacific Ocean, including the Gulf of California, Hawaii, and Micronesia.

Most animals in the sea ultimately are consumed by predators, even though they are armed with defenses molded through generations under predation pressures. But every successful defense evokes a modified offense, and thus a delicate balance exists today between offensive tactics of predators and defensive tactics of prey. We gain insight into this balance, and the forces that shape the feeding relationships of tropical reef fishes, by considering the situations characteristic of the different segments of the diel, or day-night, cycle.

Most fishes on tropical reefs are active either by day or by night, with the diurnal species generally inactive at night and the nocturnal species remaining quiet during the day (Hobson 1965, 1968, 1972, 1974; Starck and Davis 1966; Collette and Talbot 1972; Vivien 1973). The changeover from one situation to the other is a complex process that proceeds as a well-defined sequence of events during twilight (Hobson 1972). These patterns are best illustrated by considering each segment of the diel cycle separately.

The reef in daylight

Mankind's view of the life inhabiting tropical reefs generally is what occurs during midday (Fig. 1). Fishes active on tropical reefs in daylight include the majority of highly evolved fishes in the sea, species that exhibit an especially diverse array of feeding morphologies and behaviors. Prominent forms include angelfishes (family Pomacanthidae), butterflyfishes (Chaetodontidae), damselfishes (Pomacentridae), wrasses (Labridae), parrotfishes (Scaridae), surgeonfishes (Acanthuridae), triggerfishes and filefishes (Balistidae), and puffers (Tetraodontidae). For the most part, these are colorful forms with hues arranged in distinctive, readily visible patterns. Most have highly evolved feeding mechanisms that include relatively small mouths.

Fishes that find prey on the sea floor are especially varied in their feeding morphologies and habits.

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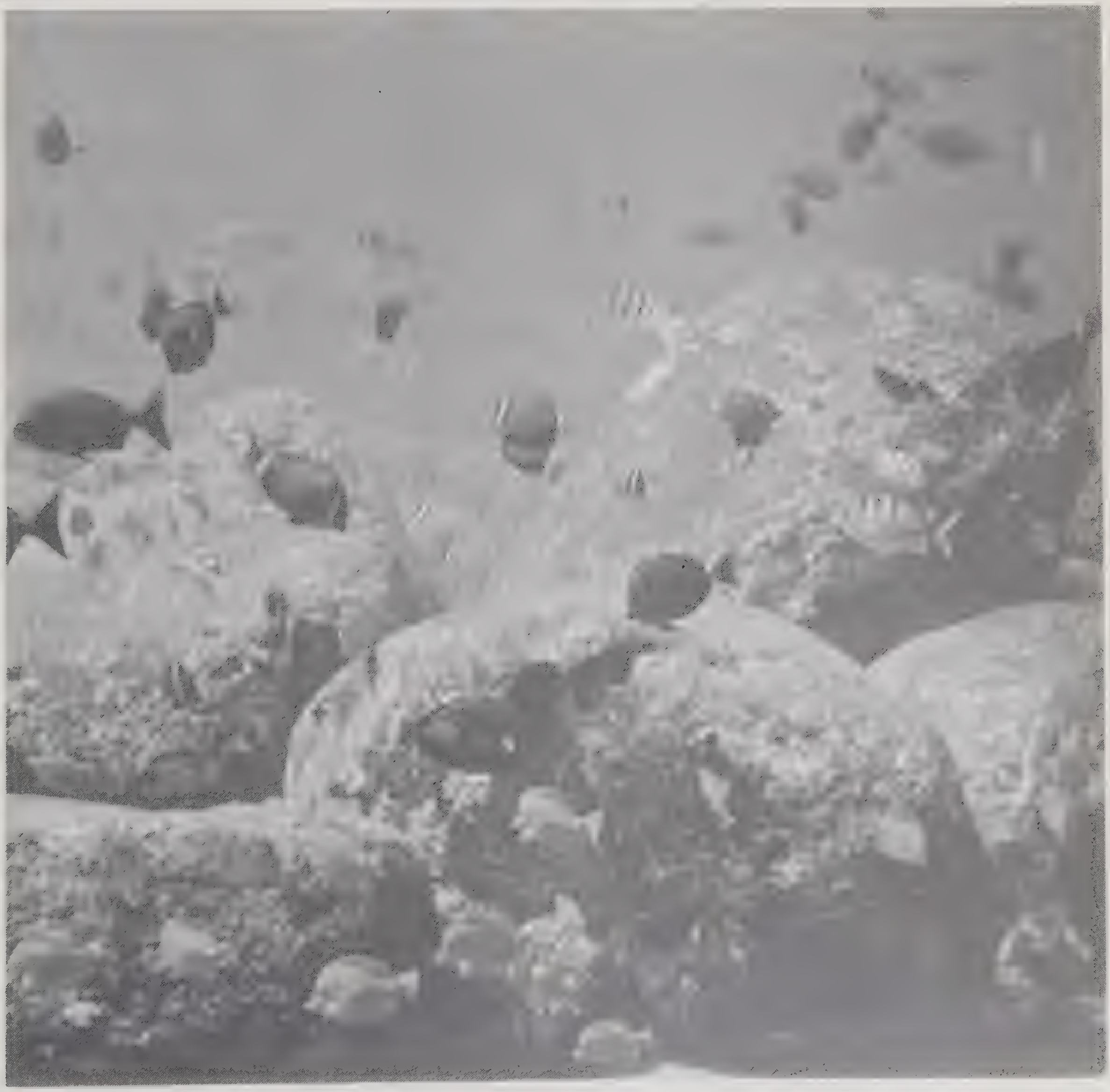
Figure 1. The fishes that swim above this Hawaiian reef during the day illustrate the great variety of forms inhabiting shallow tropical waters. Seen here are the surgeonfishes *Zebrasoma flavescens*, *Acanthurus achilles*, *A. leucopareius*, *A. nigroris*, and *Naso lituratus;* the butterflyfishes *Chaetodon lunula* and *C. quadrimaculatus;* the sea chub *Kyphosus cinerascens;* the damselfish *Abudefduf abdominalis;* and the triggerfish *Suflamen bursa.* (All photographs are by the author.)



Many have features adapted to taking tiny cryptic crustaceans, especially amphipods, from amid benthic cover. As these prey are mostly less than a few millimeters long, feeding prerequisites seem to include a small mouth that can perform precise manipulations —and the light of day. Predators that feed this way—especially certain wrasses and butterflyfishes—usually hover within a few centimeters of the reef, inspecting its surface. When they spot prey, perhaps through movement or an unusual contour, they seize it in a characteristic plucking manner (Fig. 2).

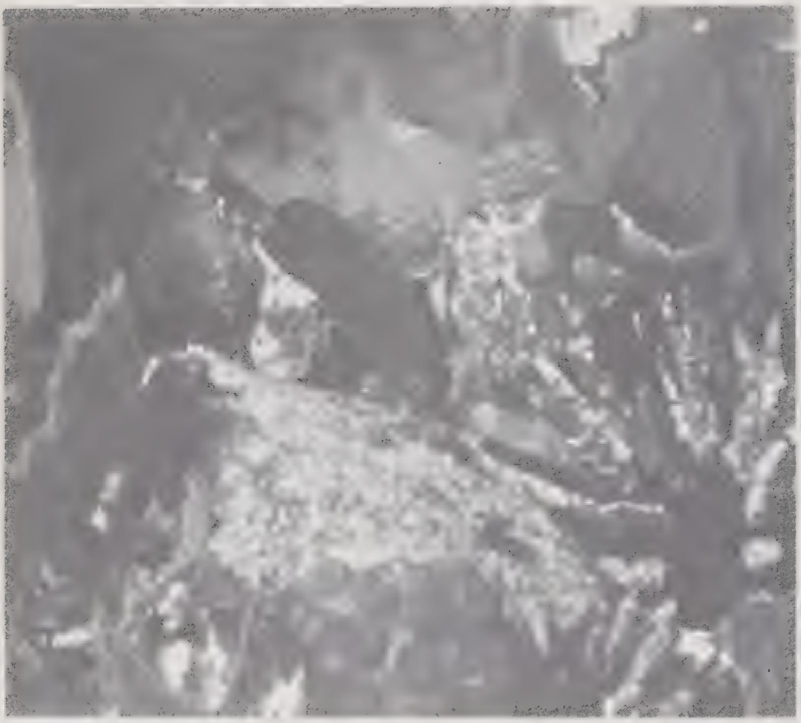


Figure 2. A damselfish, *Eupomacentrus beebei*, plucks at a tiny prey organism on a reef at the Galapagos Islands, eastern Pacific Ocean.

The morphology and behavior suited to this habit apparently have preadapted certain fishes for cleaning other animals (Hobson 1971). Cleaning—plucking ectoparasites or other deleterious material from the bodies of other animals (see Feder 1966)—is most developed among the bottom-plucking forms, especially among the wrasses (Fig. 3), damselfishes, and butterflyfishes. Apparently certain members of these groups assumed cleaning habits when their concept of an appropriate feeding substratum broadened to include the bodies of other animals.

Many other diurnal fishes possess specializations adapted to wrest motile nocturnal forms, especially various small crustaceans, from daytime resting places. The specialized predatory features used to exploit such prey are sometimes behavioral: for example, the triggerfish *Sufflamen verres* in the Gulf of California uncovers prey buried in the sand by lying on its side and rapidly undulating its dorsal and anal fins, thereby generating water currents that carry the sand away (Hobson 1968). Some small predators, certain wrasses in particular, characteristically hover close to the feeding jaws of large animals that disturb the sea floor, especially certain herbivores, and snap up small fishes and crustaceans as they are driven from hiding (Hobson 1968). Other predators have specialized anatomical features that provide access to prey hidden beyond the reach of more generalized forms; the Pacific butterflyfish *Forcipiger longirostris*, for example, uses its elongated snout to probe reef crevices for small shrimps that are secreted there.

Distinct from the above, the goatfishes (family Mullidae) are bottom-feeders that locate hidden prey by sensory means other than vision: they probe the sea floor with two relatively long sensory barbels carried beneath the lower jaw. One might suppose that fishes thus equipped would feed with equal effectiveness day and night, but that is untrue. Although all goatfishes are similarly equipped, and some hunt regularly during both day and night, others are primarily diurnal, and still others predominantly nocturnal (Hobson 1974). The diel activity pattern of each goatfish probably relates to the differential day-night habits of its specific prey. Some diurnal goatfishes, for example *Parupeneus multifasciatus* in Hawaii, feed heavily on nocturnal forms, especially xanthid crabs, that are concealed in daytime shelters.

Most predators that feed on the benthos in daylight, however, take more accessible prey, including such prominent sessile forms as sponges, coelenterates, and tunicates, as well as various slow-moving animals like echinoids and gastropods. Most of these prey organisms are fortified by such protective devices as heavy armor, nematocysts, spicules, spines, or tough fibrous tissues, and many are secreted by day deep in reef crevices or under the sand—though less consistently than the mobile secretive forms discussed above. Because of such varied defenses, the specialized feeding structures and techniques of fishes that feed on these organisms are equally varied, thus further contributing to the diversity characteristic of fishes that are active on the tropical reefs during the day.

It is well known that relatively few fishes—all highly specialized—prey on coelenterates and sponges (Hiatt and Strasburg 1960; Randall and Hartman 1968). Certain fishes that feed on individual coral polyps, including such Pacific species as the butterflyfish *Chaetodon multicinctus* and the filefish *Oxymonacanthus longirostris,* tend to have protruding snouts and teeth that project from small mouths. These features permit them to snip off scleractinian coral polyps despite the surrounding calcareous armor. Another coral-feeding filefish in the Pacific, *Cantherines dumerili,* has especially powerful jaws and strong teeth, with which it bites off chunks of the skeletal rock that includes many polyps. Some species that depend on scleractinian corals for food feed not on the polyps themselves but on the mucus that the polyps have produced. Thus, the Pacific butterflyfish *Chaetodon ornatissimus,* a comparatively blunt-snouted species, scrapes away mucus that has concentrated over abrasions on the coral surface (Fig. 4).

As for sponge-feeders, the moorish idol, *Zanclus cornutus,* and the black-striped angelfish, *Holacanthus arcuatus,* are among those few specialized fishes in Hawaii that feed mainly on sponges. The moorish idol uses its long snout to reach small sponges that live within reef crevices, whereas the black-striped

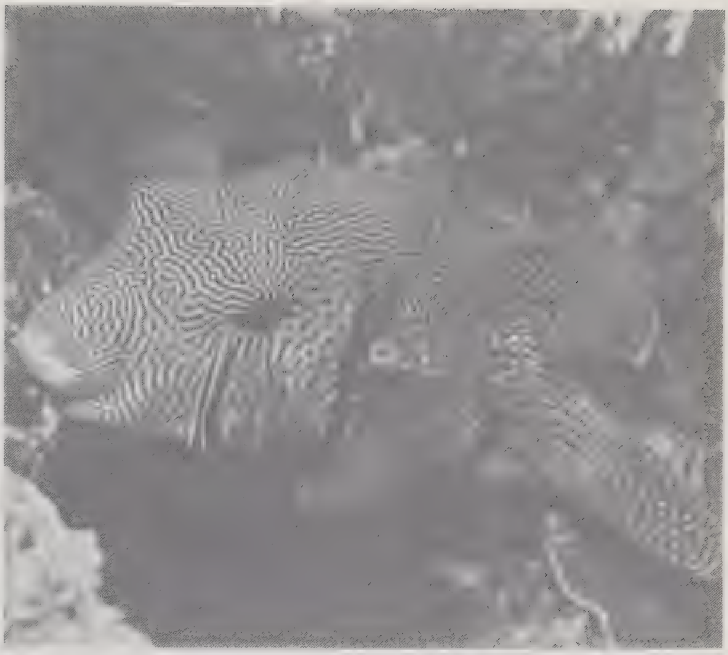
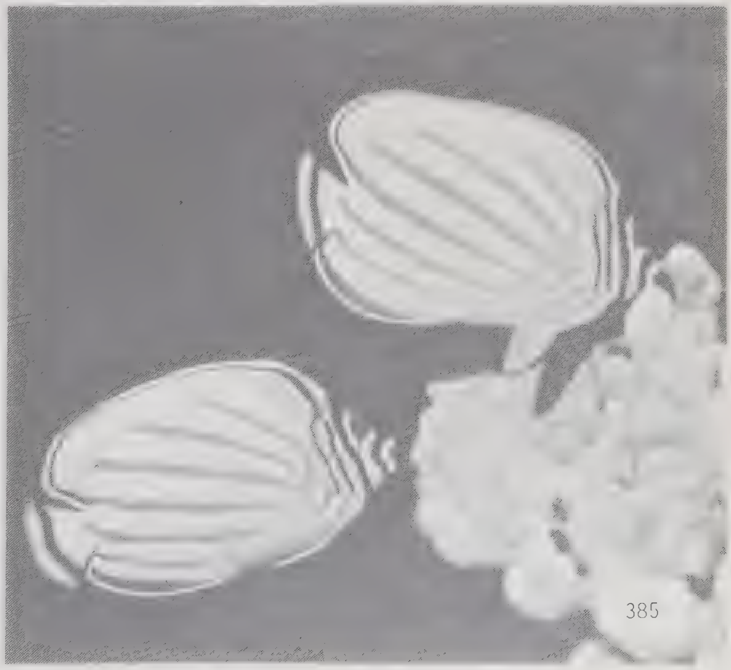


Figure 3. A small yellow, black, and blue wrasse, *Labroides* sp., cleans around the eye of a large balloonfish, *Arothron* sp., at the Palau Islands, western Pacific Ocean.

Figure 4. Butterflyfish, *Chaetodon ornatissimus,* scrape tissue and mucus from coral on a Hawaiian reef.



angelfish, lacking a long snout but having more powerful jaws, takes larger sponges that encrust the more accessible rock surfaces.

Vegetation carpets many areas of most reefs and would seem ready food for fishes. The herbivorous habit, however, is an advanced trait among marine fishes (Hiatt and Strasburg 1960) and has been acquired by only a relatively few species; nevertheless, these few often predominate on tropical reefs.

The distinction between herbivorous and carnivorous groups is not sharp. The surgeonfishes, for example, include not only many predominant reef herbivores but also species that feed heavily on organic sediments and species that prey strictly on zooplankton (Jones 1968). Furthermore, there are herbivores among the butterflyfishes, damselfishes, blennies, triggerfishes, filefishes, and other families whose carnivorous representatives are discussed above. Within these groups we can see how characteristics adapted to plucking benthic invertebrates have been modified in some species for grazing on plants. It follows, then, that most herbivorous coral-reef fishes share certain characteristics with their carnivorous relatives: both groups tend to be colorful, diurnal animals with small mouths that are part of highly evolved digestive equipment.

In the waters above the reef, clusters of small fishes hover throughout the day (Fig. 5). Most of them, including many butterflyfishes and damselfishes, prey on zooplankters, especially calanoid copepods. Others, however, including certain triggerfishes, feed heavily on drifting fragments of vegetation. As do most of the varied species that take organisms from the sea floor during the day, these planktivores have relatively small mouths. But whereas the bottom-feeder's mouth usually is directed downward from its head, that of the planktivore is usually upturned. Because the upturned mouth shortens its snout, the planktivore is better able to see tiny prey in the water immediately ahead (Walter A. Starck II, cited in Rosenblatt 1967).

Diurnal plantivorous fishes have converged not only in their feeding equipment but also toward having fusiform bodies and deeply incised (forked or lunate) caudal fins. Both of these features are also widespread among oceanic fishes like tunas and are linked to the ability to swim rapidly. Thus, one would expect diurnal planktivores that have these features to find increased speed adaptive. The advantage seems clear: small reef fishes that swim in open water, high above the sheltering reef, benefit from added speed to elude the predators that patrol these waters. Because they share these morphological tendencies, many unrelated diurnal planktivorous fishes (including certain damselfishes and seabasses) look, on casual inspection, more like one another than like members of their own families that feed on the benthos (see Davis and Birdsong 1973).

Many large, motile piscivorous fishes, including a variety of jacks (family Carangidae), patrol the waters above tropical reefs during the day. Yet despite their widespread presence and apparent readiness to feed, midday attacks are relatively infrequent—their major feeding successes come later (or earlier) in the day. These predators seem to find smaller reef fishes difficult targets during midday, even though they will attack when an opportunity arises. It is probably this threat of attack that keeps most smaller active fishes near the reef during the day. They may rise into the midwaters above the reef or swim out over the edge of adjacent open bottom, but generally they stay close enough to the reef so that shelter will be within reach if it is needed.

Similarly, the threat of attack probably is a major reason why so many small fishes aggregate when active in exposed locations. Even fishes that are solitary when close to reef cover will join others of their kind when in open water. It may be that predators have difficulty isolating a target from among the many confronting them in a fish school (Manteifel and Radakov 1961; Eibl-Eibesfeldt 1962; Hobson 1968), and thus smaller fishes are relatively secure in these aggregations. Ordinarily, smaller fishes congregated in exposed positions draw closer to one another when large predators approach (Hobson 1965, 1968).

Selective pressures from generations of visually orienting predators have refined defense mechanisms that protect prey species in daylight. There are, of course, occasional lapses in these defenses when the prey are briefly vulnerable. Small fishes that usually stay within retreating distance of cover sometimes stray too far into the open, and others normally secure in a school occasionally drift too far from their fellows. Often large jacks or other predators swim slowly among schooling prey for hours during the day without an aggressive move, and then suddenly attack—presumably having sensed a vulnerable target. But potential prey are sensitive to hunting predators; when one appears, they become especially alert, and thus less likely to make a defensive mistake.

The problem of being within striking range when small fishes become momentarily vulnerable during the day because of a defensive lapse has been solved by predators that lie in wait under cover or camouflaged—the ambushers—or by those that stalk. These tactics are used by some highly specialized forms. Typically, the ambushers are cryptically hued forms that remain unseen as they rest immobile on the sea floor. From here they attack unwary prey that stray within reach of a sudden explosive charge. Ambushers include lizardfishes, scorpionfishes (Fig. 6), and flatfishes. The stalkers, on the other hand, must arrive within striking distance of vulnerable prey while they themselves are in full view. They do this by drifting slowly toward smaller fishes, showing overt aggression only when close to an unwary victim. The stalkers—typically long, attenuated fishes—include barracuda (family Sphyraenidae), needlefishes (Belonidae), trumpetfishes (Aulostomidae), and cornetfishes (Fistulariidae).

Many fishes are adapted for life in the caves and crevices that honeycomb tropical reefs. Prominent

Figure 5. Damselfishes rise into the waters above a reef at the Palau Islands, where they will feed on zooplankters.

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among them are the moray eels, which remain largely unseen on the reef top even though they are among the predominant fishes in the area. Although generally described as nocturnal, many morays are in fact most active during the day (Hobson 1968, 1974; Chave and Randall 1971). Some of them forage in exposed locations, but most confine their activities to reef crevices. Many specialized features, including an extremely solid skull and an elongated body, enable moray eels to wedge through narrow spaces within the reef (Gosline 1971).

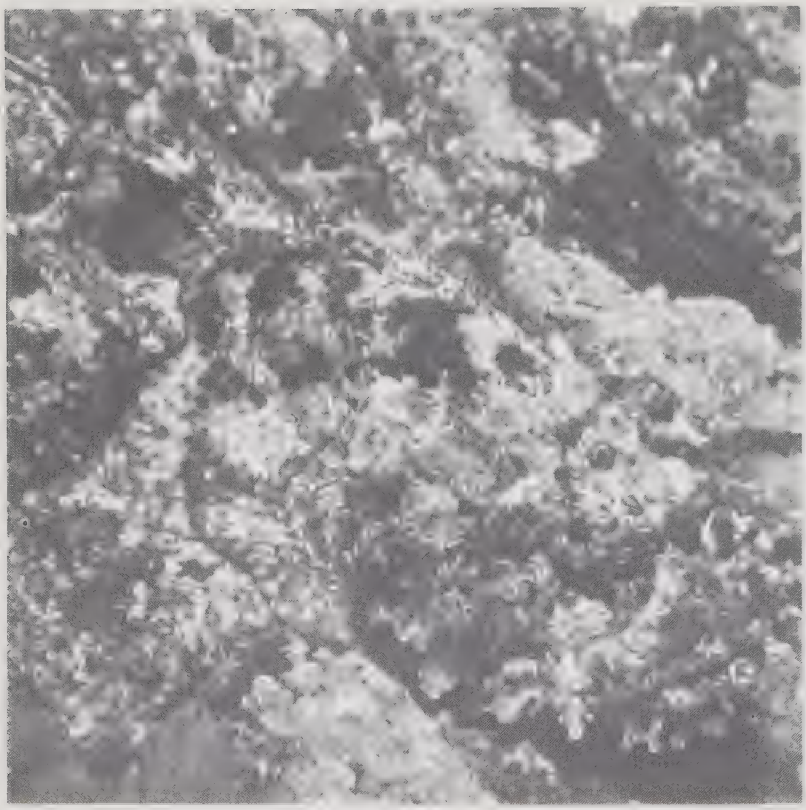


Figure 6. A scorpionfish, *Scorpaena* sp., lies virtually unseen on a reef at the Galapagos Islands, where it will attack small fishes and crustaceans that venture near.

Besides being home for organisms that remain secreted at all hours, the caves and crevices are daytime havens for many other forms seeking shelter when injured or distressed. It is not surprising, therefore, that many morays and other predators in these places respond quickly to stimuli emanating from fishes in distress. Thus, although many organisms find reef crevices a haven from predators that hunt on the surface of the reef, they become vulnerable in those shelters to other predators, including moray eels, that have developed adaptive means to exploit this situation.

Some of the more prominent fishes on the reef during the day are in fact nocturnal forms that assemble here in large, stationary schools while inactive. Included are many of the herrings (family Clupeidae), silversides (Atherinidae), grunts (Pomadasyidae), snappers (Lutjanidae), and croakers (Sciaenidae). Although fish in these schools are a major component of the daytime scene on many tropical reefs, most leave the reef at nightfall and forage elsewhere.

Other nocturnal fishes make themselves less conspicuous during the day by assembling in reef crevices and caves. Included in this category are many of the squirrelfishes and soldierfishes (family Holocentridae), cardinalfishes (Apogonidae), bigeyes (Priacanthidae), and sweepers (Pempheridae). Although most are out of sight during daylight, some frequently are visible around the bases of coral heads or at the openings to caves (see cover).

The reef during twilight

A human observer has difficulty recognizing when the daytime situation first begins moving toward the nocturnal mode. The early transition is indistinguishable from variations in activity during midday when light levels fluctuate with changing cloud cover and water transparencies. Within the hour before sunset, however, the transition events are unmistakable.

Probably the first obvious sign of changeover occurs among the planktivorous fishes. After having been aggregated in the midwaters above the reef throughout the day, these fishes descend progressively closer to the reef as light diminishes (Hobson 1972; Collette and Talbot 1972). By the time they are in the lower regions of the water column, it is clear that many other diurnal fishes are similarly moving closer to cover. The sequence in which they shelter themselves varies with species and size. For example, the wrasses are among the first to settle down, and among all species that shelter at nightfall the smaller individuals are first to move from view. By sunset many diurnal fishes are no longer visible, and the numbers of others in the water column rapidly diminish.

At the same time that many diurnal fishes are leaving the water column, others, including certain parrotfishes, surgeonfishes, and damselfishes, move in long drawn-out processions from one part of the reef to another. Clearly, many reef species redistribute themselves at this time, in essence moving between feeding grounds and resting places that sometimes are widely separated. Certain species follow the same routes at the same time, relative to sunset, day after day. The patterns remain poorly defined, however, because instead of joining the movements, many individuals of these same species find cover where they have been active throughout the day (Hobson 1972).

More and more diurnal fishes take cover as twilight progresses, but a substantial number still occupy the lower regions of the water column 10 to 15 minutes after sunset. Then, abruptly, the vast majority drop to the reef below, leaving the water column essentially deserted.

Now there ensues on most reefs a span of about 20 minutes that can aptly be called the quiet period. At the outset, many diurnal species still mill about close among the coral, but their activity steadily diminishes. Prominent among them are certain surgeonfishes, damselfishes (Fig. 7), and butterflyfishes, some already showing colorations different from those of daylight. Amid these increasingly inactive diurnal fishes some nocturnal forms begin to circulate, having emerged from the reef crevices that harbored them in daylight. Usually these include some of the larger cardinalfishes and squirrelfishes, which remain close to the reef. Despite this activity, however, the reef overall appears still.

About 30 minutes after sunset, hordes of soldierfishes and other nocturnal species come boiling out of their caves. These are fishes that will forage up in the midwaters during the night, and their sudden appearance abruptly ends the quiet period. It is now almost dark, and a human observer can just dimly distinguish in the last vestige of rapidly fading daylight the major features of the reef around him.

One might wonder why these crepuscular events follow a well-defined sequence, and why, during that quiet segment of twilight, both diurnal and nocturnal reef fishes are largely absent from the midwaters. Answers to these questions, I believe, become evident if one observes places where large fish-eating predators find their prey concentrated and accessible, as for example in large schools. Many predators apparently find dusk's half-light to their advantage, and under appropriate circumstances certain

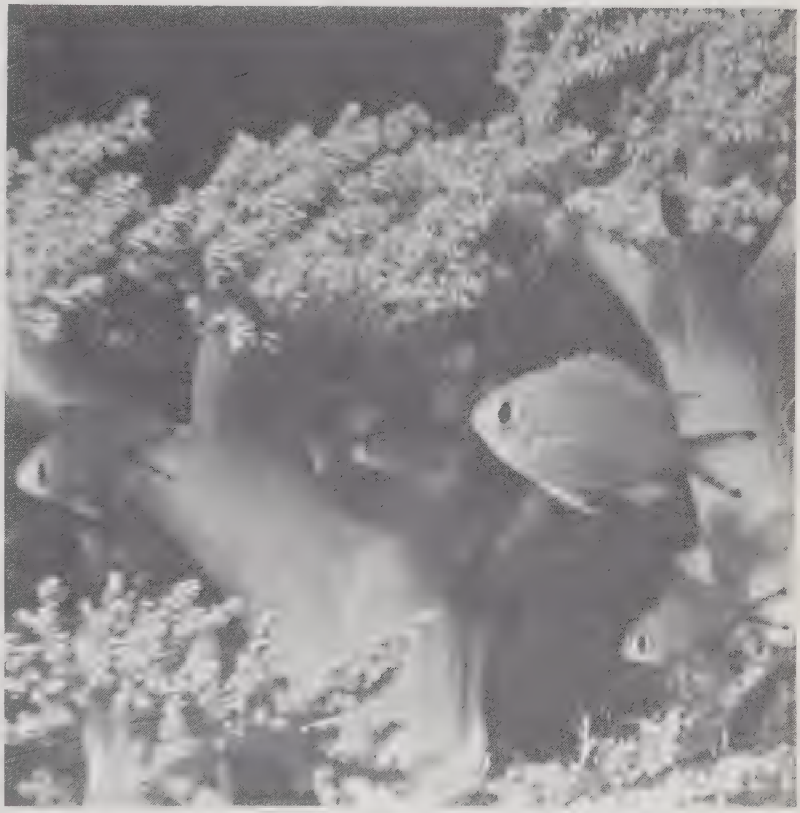


Figure 7. At day's end, damselfish, *Chromis lepidolepis*, shelter among soft corals at the Palau Islands.

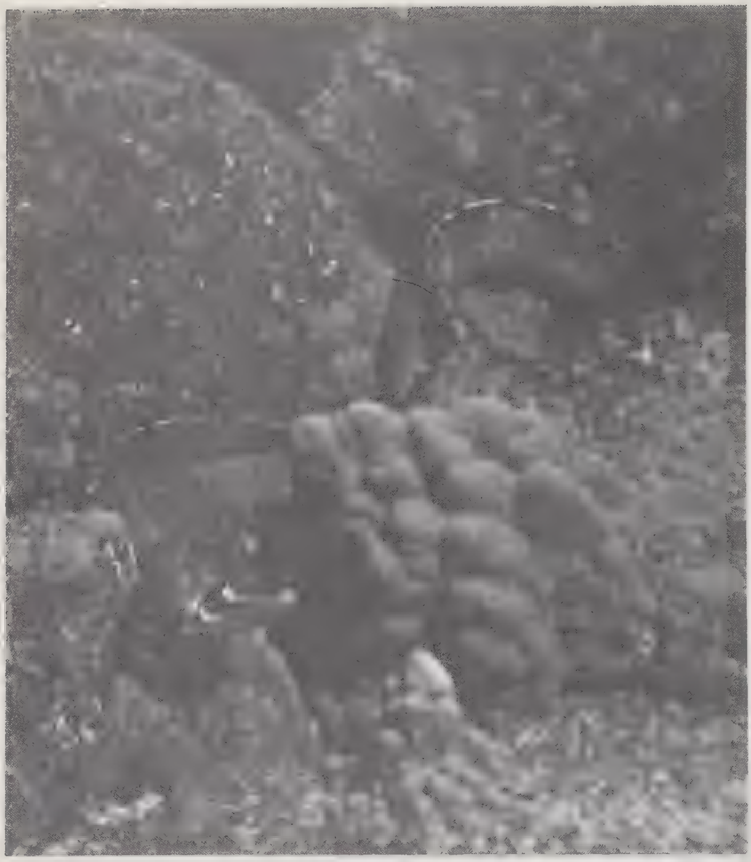


Figure 8. A moray eel, *Gymnothorax petelli*, hunts for prey on a Hawaiian reef at night.

Figure 9. Two parrotfishes, *Scarus sordidus* (on the left) and *S. dubius*, are protected from predators by a mucus covering as they rest under a coral ledge in Hawaii at night.

large piscivores whip the sea into a froth of predatory activity during that same period of twilight that is quiet on so many other reefs.

These crepuscular attacks can be seen in certain parts of the Gulf of California, where massive schools of herrings, grunts, and other species concentrate near shore. Although members of these schools are relatively safe from predators during most of the day, the mechanism providing this protection seems increasingly ineffective during twilight (Hobson 1965, 1968). In their attacks, jacks and other large predators need room to maneuver, and, as we have seen, most small reef fishes, by moving close to the reef, shelter themselves from such attacks during this vulnerable period. But havens amid reef structures cannot be used by most schooling fishes, which must face predators in relatively open water.

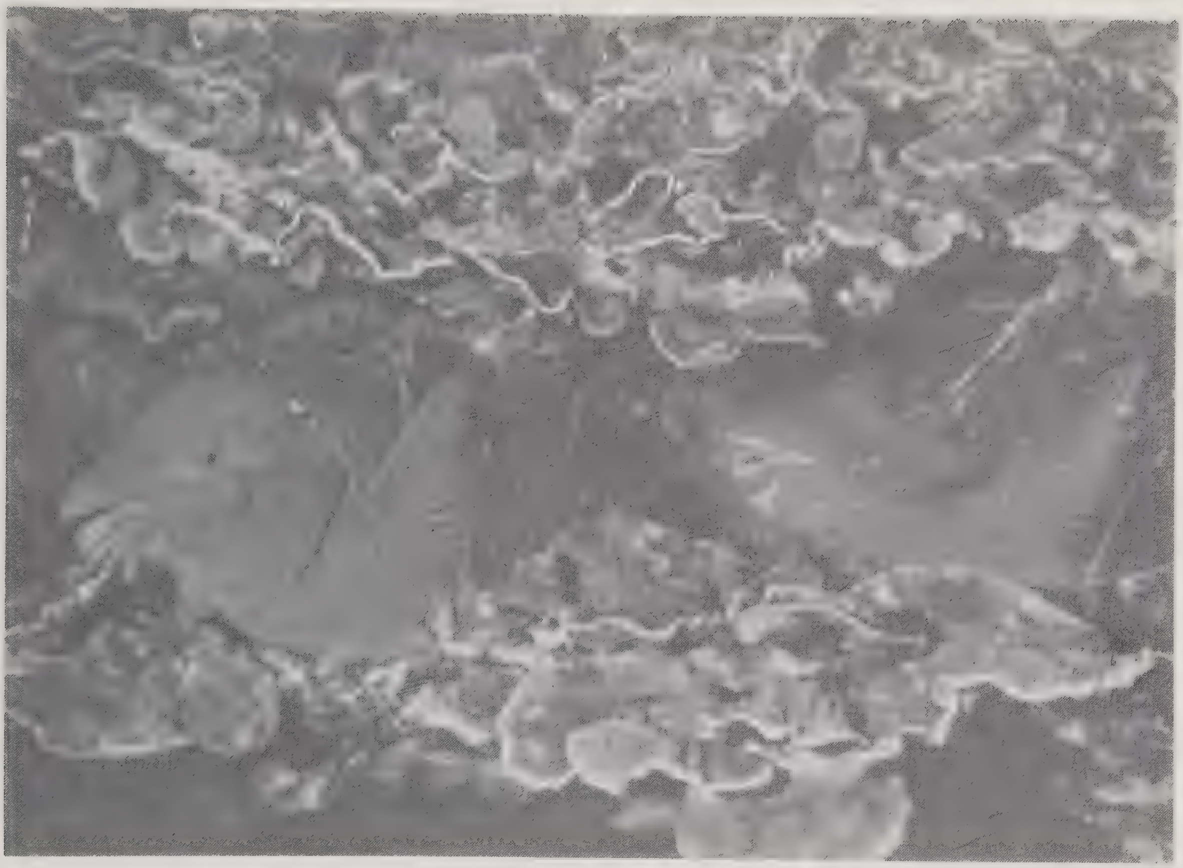
Although the large piscivores seem to attack most effectively in the reduced light of dusk, their attacks abruptly diminish about 30 minutes after sunset, suggesting that they become ineffective when light falls below a certain level. Not surprisingly, schooling fishes that endure these crepuscular attacks generally remain close together until their attackers have withdrawn (Hobson 1968). And, significantly, at about the same time that the schooling fishes disperse over their nocturnal feeding grounds, nocturnal soldierfishes are streaming out of their reef caves to end the quiet period (Hobson 1972).

The threat from crepuscular predators, I believe, has shaped the twilight activities of tropical reef fishes into an established, well-defined sequence of events. The reef undergoes a quiet period when large piscivores are relatively few or dispersed and when schooling fishes are insignificant. But even when overt attacks are infrequent, the advantage of proximate cover during this period is probably strong. Significantly, the sequence of events characterizing activities of reef fishes during evening twilight is essentially reversed during the corresponding period of morning twilight (Hobson 1972).

The reef after dark

Having reoccupied the midwaters above the reef at nightfall, some of the soldierfishes forage there on zooplankters until daybreak, but many others mass together and swim offshore to feed. Bigeyes are among the species that behave similarly (Gosline 1965; Hobson 1972). The soldierfishes and others that migrate to off-reef feeding grounds behave much like the many schooling fishes that perform similar migrations at nightfall.

On the reef below, meanwhile, many other nocturnal fishes, including squirrelfishes (genera *Adio-*



ryx, Flammeo, Holocentrus, and *Holotrachys*) and scorpionfishes (*Dendrochirus, Pterois,* and *Scorpaena*), have emerged from the caves that harbored them in daylight and will hunt close among the coral throughout the night. Many moray eels, too, as well as conger eels (family Congridae) swim on the darkened reef-top, most of them in transit from one crevice to another (Fig. 8).

Despite the nocturnal hunters, however, a casual observer sees relatively little activity on the reef at night. Compared to the many fishes one sees there in daylight, few are visible after dark. Even discounting all those fishes that leave the reef at nightfall to forage elsewhere, there seems a dearth of active fishes among the darkened corals. Nocturnal fishes tend to be inconspicuous, most being rather small (less than 30 cm long) and only intermittently exposed close to shelter on the reef-top. Moreover, in comparison to the many diurnal fishes that display bright hues in bold patterns, most nocturnal fishes are drab.

The nocturnal fishes are predators, most with large but relatively simple mouths. The diverse array of specialized feeding structures and behaviors found among diurnal reef fishes are largely missing among fishes active at night. Most of these features are adaptations for coping with the formidable defensive structures that protect such highly varied sessile organisms as sponges, corals, and tunicates, and fishes that forage at night prey insignificantly on these forms, perhaps because in the dark they cannot detect prey that do not move (Hobson 1968, 1974).

The major prey of nocturnal fishes are motile crustaceans, most about 2 to 10 mm in their greatest dimension. They are small enough for a fish under 30 cm to swallow whole, which is the way most of them feed, yet large enough for a fish this size to entrap in its relatively large mouth. The majority are nocturnal creatures that rest under cover during the day, secure from all but diurnal predators specialized to seek them out. Upon moving into the open at night, they become exposed to direct attacks of generalized predators that can operate in the dark.

Of course, there are nocturnal fishes that take prey from other than exposed locations. Examples include the nocturnal goatfishes, which use their sensory chin barbels just as their diurnal relatives do—to probe the sea floor for hidden prey. At least one, the Hawaiian *Parupeneus bifasciatus* (which feeds regularly during both day and night), preys after dark on such diurnal fishes as blennies and damselfishes, probably taking them from where they shelter themselves at night (Hobson 1974). Other examples include eels, both morays and congers, that actively hunt prey among reef crevices after dark.

Although most nocturnal fishes have relatively simple feeding equipment, they tend to have large eyes, and several prominent species are highly specialized. For example, the spiny puffers (family Diodontidae) have powerful beaklike jaws, with massive crushing plates, with which they ingest large, heavily armored prey like gastropods and echinoids that move slowly on the reef after dark.

The soldierfishes, and others that predominate in the midwaters above the reef at night, take zooplankters unlike those taken by fishes that forage in these same places during the day. The diurnal planktivores take primarily small, full-time residents of the water column, like calanoid copepods, cladocerans, and larvaceans. Although these zooplankters are equally numerous in the water column after dark, when calanoids, at least, are important prey of certain smaller nocturnal planktivores, including many herrings, silversides, and juveniles of other species, the soldierfishes and other larger nocturnal planktivores direct their attacks instead at forms like mysids, crab megalops, and nereid polychaetes. (I use a broad, perhaps loose, concept of the term *zooplankton* here). These prey tend to be larger than zooplankters taken by diurnal fishes, and, like many of their nocturnal predators, most rise into the midwaters at nightfall from daytime positions on, in, or close to the sea floor.

Nocturnal planktivores, like their diurnal counterparts, tend to have sharply upturned mouths (presumably related to taking small prey from open water), but their mouths generally are larger than those of the diurnal species, which is consistent with the larger size of their prey. Some major characteristics common among diurnal planktivores, however—especially their increased tendencies toward fusiform bodies and deeply incised caudal fins—are less evident among planktivores in the midwaters at night. Soldierfishes, for example, are actually deeper-bodied than most of the bottom-feeding members of their family. If these features are adaptive because they provide added speed to elude predators in open water, then the general absence of such features among small free-swimming species that rise into the midwaters at night suggests that there is a diminished threat from piscivorous predators in the water column after dark (Hobson 1973, 1974). One arrives at this same conclusion when considering the many other fishes that spend the day close to shelter on the reef —in schools or congregated in crevices—but that range out into exposed locations at night.

Further evidence bearing on the relative threat of large piscivorous predators to reef fishes at night is found among the many diurnal species that rest on the bottom after dark. The smaller individuals (less than about 15 cm) move out of sight into crevices at nightfall, indicating that they would be vulnerable in the open. But some moderately sized (over about 18 cm) butterflyfishes, surgeonfishes, and others rest in exposed or semiexposed positions, seemingly unthreatened. On the other hand, the mottled coloring that some diurnal fishes assume when they rest on the sea floor at night would seem to have selective advantage in making them less visible to nocturnal predators (Schroeder and Starck 1964). Furthermore, the mucous sheaths that some smaller parrotfishes and wrasses secrete around themselves at night (Fig. 9) are probably adaptive because they protect these fishes from predators, especially those moray eels that detect prey by direct contact with sensory receptors on their snouts (Bardach, Winn, and Menzel 1959).

Adaptions related to feeding—either to improve the fish's ability to obtain food or to elude predators —account for most of the great diversity of form among tropical reef fishes. Clearly, the evolution of these adaptations has been influenced from the beginning by factors associated with the different segments of the diel cycle.

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FIRST CALIFORNIA RECORD OF THE SERRANID FISH *ANTHIAS GORDENSIS* WADE

EDMUND S. HOBSON

During February, 1974, James R. Chess and I collected a single specimen of *Anthias gordensis* Wade, 102 mm (4 inches) standard length (SL) (Figure 1), at Ship Rock, Santa Catalina Island (33° 28′ N, 118° 29′ W). When speared, this fish was the only member of its species seen amid a large aggregation of blacksmith, *Chromis punctipinnis*, that hovered close above a rocky ledge at a depth of about 40 m (132 ft). The specimen, now in the fish collection at Scripps Institution of Oceanography (SIO 74-22), was identified by Richard H. Rosenblatt of that institution.

Anthias gordensis was described by Wade (1946) from a 127 mm (5 inch) SL holotype and a 130 mm (5.1 inch) SL paratype, both dredged at a depth of about 150 m (495 ft) near inner Gorda Bank, Cape San Lucas, Lower California, Mexico. Dr. Rosenblatt (pers. comm.) observed large numbers of this species from the Cousteau diving saucer at depths between 100 and 200 m (330 and 660 ft) at Cape San Lucas, but because this fish inhabits infrequently sampled deeper reefs, relatively few specimens have been collected. Until now, the northernmost record of the species is a single individual 205 mm (8.1 inches) SL taken near the bottom 110 m (363 ft) deep at Guadalupe Island, Mexico (29° N, 118° 30′ W), by Albert Stover, Scripps Institution of Oceanography (SIO 63-161).

Only one other species of this genus has been reported from the eastern Pacific: *Anthias sechurae* (Barton) from Peru, based on a 188 mm (7.4 inch) SL holotype and a 192 mm (7.6 inch) paratype (Barton 1947). Hildebrand and Barton (1949) recognized that *A. sechurae* may be a junior synonym of *A. gordensis*, with differences in descriptions being partly due to differences in size between type specimens, but the question remains unresolved.

The following combination of characters of the specimen from Santa Catalina Island confirm its identity: dorsal X, 15; anal III, 7; body depth and head both 3 in standard length; eye 3.7 in head; scales ctenoid, 48 on lateral line; head and maxillary scaled, dorsal and anal fins without scales.

Stomach contents of the specimen from Santa Catalina Island, identified by James R. Chess, and ranked as percentage by volume of identifiable material, were as follows: 67 calanoid copepods, 0.6 to 1.2 mm (0.02 to 0.05 inch) long, 75%; 14 cyclopoid copepods, 0.8 mm (0.03 inch) long, 10%; 6 euphausid larvae, 1.0 mm (0.04 inch) long, 5%; and 9 fish eggs, 1.0 mm (0.04 inch) in diameter, 10%. Clearly this fish is a planktivore, as is the blacksmith (Quast 1968), with which it was swimming when collected.

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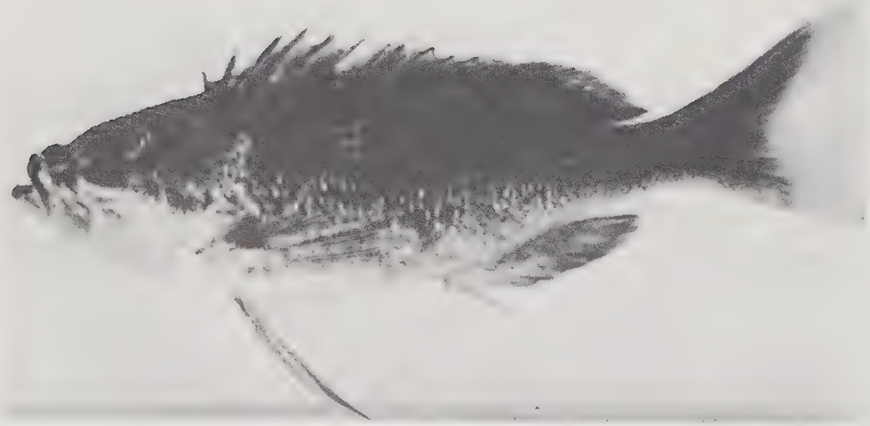

FIGURE 1. Specimen of *Anthias gordensis* Wade, 102 mm SL, collected at Santa Catalina Island (SIO 74-22).

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NOTES

TWO BLOOMS OF *GYMNODINIUM SPLENDENS*, AN UNARMORED DINOFLAGELLATE

Little is known about the ecology and physiology of an unarmored dinoflagellate (30 to 50 µm), *Gymnodinium splendens* Lebour, although feeding experiments have shown it to be an important food source for certain marine herbivores. Lasker et al. (1970) found that anchovy larvae may be reared the first week upon unialgal suspensions of *G. splendens* while Paffenhöfer (1970, 1971) and Barnett (1974) showed it to be a preferred food for *Calanus finmarchicus* and larval stages of *Labidocera trispinosa*. Pokorny and Gold (1973) reported on cell ultrastructure of *G. splendens*, Sweeney (1954) observed vitamin B_{12} requirements, and Thomas et al. (1973) described optimal light and temperature requirements. In addition to these laboratory studies, Loftus et al. (1972) have noted *G. splendens* in a bloom of diverse dinoflagellate species in Chesapeake Bay.

This note reports upon two field studies of blooms of *G. splendens*. The first observation was made in Coyote Bay of Bahia Concepción, Gulf of California, where *G. splendens* was the dominant phytoplankter in March 1971. The second observation was made in March 1974, when large concentrations were observed in coastal waters of the Southern California Bight. In both occurrences *G. splendens* dominated the phytoplankton crop so that measurements of primary production and the chemical composition of suspended particles allowed a reasonable description of this species.

Gymnodinium splendens in Coyote Bay

Coyote Bay (lat. 26°43.0′N, long. 111°53.0′W) of Bahia Concepción is well protected and shallow. Chemical and physical observations were made while the ship (RV *E. B. Scripps*) was at anchor in 20 m of water and included measurements of particulate adenosine triphosphate (Holm-Hansen and Booth 1966) and chlorophyll (Yentsch and Menzel 1963; Holm-Hansen et al. 1965), microscopic examination of water samples preserved in 5% (V/V) buffered Formalin[1] (Utermöhl 1958), and determinations of primary production based upon rates of incorporation of radioactive carbon (Steemann Nielsen 1952). The depth distribution of phytoplankton was recorded at regular intervals by continuous vertical profiles to the bottom with both a submersible transmissometer (Petzold and Austin 1968) and a fluorometer attached to a hose and submersible pump (Lorenzen 1966; Kiefer and Austin 1974). The continuous profiles of in situ fluorescence were translated into chlorophyll *a* concentrations by frequent calibration with discrete samples which were analyzed fluorometrically for chlorophyll and phaeophytin concentration (Kiefer 1973).

The five phytoplankters which occurred together and were numerically most abundant in Coyote Bay were: *G. splendens* (1.0×10^5/liter), *Leptocylindrus danicus* (3.4×10^4/liter), *Skeletonema costatum* (1.4×10^3/liter), *Cerataulina bergonii* (1.4×10^3/liter), and *Thalassiothrix frauenfeldii* (4.0×10^3/liter). Chlorophyll concentration varied with depth and ranged from 4.4 µg/liter to 13 µg/liter for numerous samplings of the 20-m water column. Figure 1 shows a time sequence of profiles of in situ fluorescence of chlorophyll. Profiles of light transmission displayed a similar stratified structure. The increase in depth of the upper chlorophyll maximum between 1845 and 2300 and the decrease in depth between 2300 and 0720 the following day indicated a diel migration of *G. splendens*. This suggestion was supported by the predominance of *G. splendens* in the maxima and by the improbability of physical factors such as advection or internal waves affecting such variations. Conditions were calm at the sea surface and the water column was isothermal with depth.

The upper chlorophyll maximum (Figure 1) moved downward at sunset with a velocity of approximately 1.7 m/h. Such velocities are similar to those of other dinoflagellates. For example, a natural bloom of *Ceratium furca* occurring off the southern California coast was observed to migrate downward at 2 m/h and mass cultures of *Cachonina niei* and *Gonyaulax polyedra* displayed migratory rates of 1 to 2 m/h (Eppley et al. 1968). Our observations suggested that a portion of the *G. splendens* population moved upward between 2300 and 0400 the following day. Since sunrise was

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[1] Reference to trade names does not imply endorsement by the National Marine Fisheries Service, NOAA.

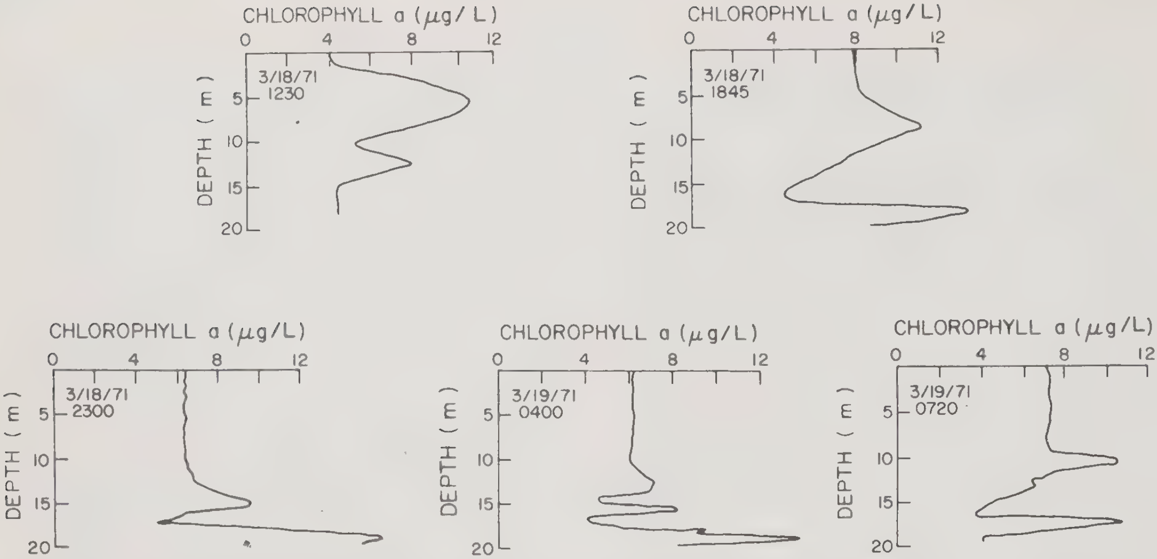

FIGURE 1.–Profiles of the concentration of chlorophyll *a* based upon fluorescence profiles. The upper layer of *Gymnodinium splendens* at 1230 h was concentrated at 6 m; by 1845 it had moved to 8 m and reached 15 m by 2300. Movement upward commenced at 0200 reaching 10 m by 0720. The lower layer remained relatively close to the bottom during this time.

around 0600, this movement may originate from a biological clock rather than from a phototactic response. These observations partially conflict with laboratory studies of phototaxis in *G. splendens* (Forward 1974). He found that not only was the cell strongly phototactic but that the strength of the response was subject to a circadian rhythm, being strongest at the end of the entrained dark period.

By assuming that *G. splendens* dominated the production as well as the standing crop of phytoplankton in Coyote Bay, we obtain information on the steady state doubling time for the species. Water samples were collected from four depths, 0, 5, 10, and 18 m, inoculated with $NaH^{14}CO_3$, and incubated from sunrise to sunset in situ. Primary production was then determined from rates of light-induced incorporation of ^{14}C into particles removed by filtration. The water samples were also analyzed for concentrations of chlorophyll *a* and adenosine triphosphate (ATP). By multiplying the concentration of ATP by 250, we obtained an estimate of "living-carbon" (Holm-Hansen and Booth 1966); this estimate allowed a crude determination of doubling time t_d from the steady-state equation:

$$t_d = \frac{\ln 2}{\mu} = \frac{C \cdot \ln 2}{\Delta C / \Delta t}$$

where μ is the specific growth rate and equal to the rate of carbon assimilation, $\Delta C/\Delta t$, divided by C, the concentration of cell carbon. On this basis, the doubling time for *G. splendens* at 0, 5, 10, and 18 m was 2.3, 2.6, 2.7, and 62 days, respectively (Table 1). These estimates of doubling time for a natural population of *G. splendens* may be compared with a maximal doubling time of 1.6 days for cells grown in the laboratory (Thomas et al. 1973). We also note that our estimates of the chlorophyll *a* concentration per cell yielded a value of approximately 100 pg/cell, typical for laboratory cultures (Bailey 1974).

TABLE 1.–Production, chlorophyll *a*, ATP, and doubling time for a *Gymnodinium splendens* bloom in Coyote Bay, Gulf of California.

Depth (m)	Production (μg C/liter•day)	Chlorophyll *a* concentration (μg/liter)	ATP (μg/liter)	Doubling time (days)
0	125	5.8	1.7	2.3
5	108	5.3	1.6	2.6
10	126	6.2	1.9	2.6
18	35	4.7	1.3	62

Gymnodinium splendens in the Southern California Bight

A second bloom of *G. splendens* was observed in March 1974, along the southern coast of California, during a cruise on RV *David Starr Jordan*. Stations in the sampling program extended along the 20-fathom contour from Malibu (lat. 34°00.8′N, long. 118°40.6′W) south to San Onofre (lat. 32°56.0′N, long. 117°17.4′W). Intermediate stations included Manhattan Beach (lat. 33°52.5′N, long. 118°27.0′W), Seal Beach (lat. 33°36.5′N, long. 119°04.3′W), and Dana Point (lat. 33°26.3′N, long. 117°42.8′W). A sixth station was on the 270-fathom contour off Laguna Beach (lat. 33°30.8′N, long. 117°50.3′W).

Continuous vertical profiles of in situ chlorophyll fluorescence were made to a depth of 35 m. Water from the outflow of the fluorometer was collected at the surface and within the fluorescence maximum. Three analyses were made on subsamples of water from the two depths. First, the size distribution of suspended particles was immediately determined with an electronic particle counter (model T_a Coulter Counter). We accumulated counts in the upper nine channels which gave us a frequency distribution for particles with equivalent diameters ranging from 20 to 128 μm. Second, subsamples were preserved in 5% Formalin for species determination. Third, the chlorophyll *a* concentration in each subsample was determined fluorometrically for acetone extracts of filtered particles.

Vertical profiles made at various times of the day and night at each of the six stations on the 20-fathom contour were characterized by a unimodal distribution of chlorophyll. The chlorophyll maximum varied little in depth from 15 to 20 m within a moderately developed thermocline, and was most often less than 4 m thick. At these stations, *G. splendens* contributed most of the phytoplankton crop within the maxima. However, in surface waters it contributed a much smaller fraction of the crop. The highest concentration (Figure 2) of *G. splendens* was within the well-defined maximum at Seal Beach where its concentration reached 4×10^5 cells/liter (chlorophyll $a = 42.0\,\mu g$/liter). The lowest concentration within a maximum was at Manhattan Beach, 1.2×10^4 cells/liter (chlorophyll $a = 1.3$ μg/liter.

The predominance of *G. splendens* in the chlorophyll maximum was also evident from the particle size distributions obtained with the electronic particle counter. Within the maximum, particles with equivalent diameters between 36 and 57 μm far outnumbered smaller- and larger-sized particles. In surface waters the smaller-sized particles outnumbered particles of the size of *G. splendens*. The other phytoplankton in surface waters included *Ceratium furca* and *C. kofoidii*, *Dinophysis acuminata*, and a species of *Gyrodinium*. Very few diatoms were present.

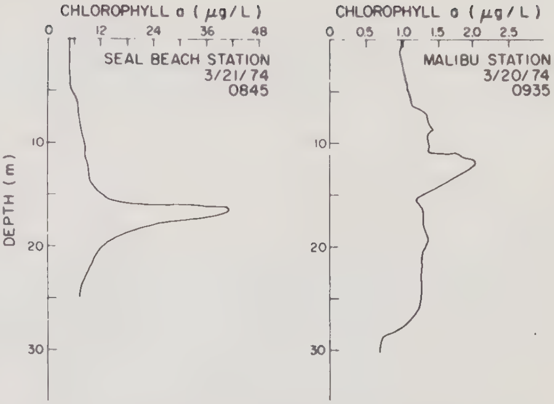

FIGURE 2.—Profiles of the concentration of chlorophyll *a* based upon fluorescence profiles at two stations along the 20-fathom contour of the Southern California Bight. The subsurface maxima are predominantly composed of *Gymnodinium splendens*.

It appeared that the bloom of *G. splendens* dissipated seaward since the subsurface chlorophyll maximum was poorly developed at the Laguna Beach station which was on the 270-fathom contour. Here the concentration of chlorophyll in the maximum was only 0.76 μg/liter, while the concentration at the surface was 0.63 μg/liter. In addition, both the particle size distribution and microscopic counts indicated a more diverse assemblage of dinoflagellate species at this station, with the unarmored dinoflagellate *Cochlodinium catenatum* being most abundant.

Thus, the bloom of *G. splendens* appeared to be limited to nearshore waters, in a band extending as far as 100 km along the coast. This subsurface bloom was presumed to be a large food source for planktonic herbivores, but more field sampling is necessary to determine whether the bloom is a seasonal occurrence. In another paper, Lasker (1975) describes the feeding responses of anchovy larvae to these natural concentrations of *G. splendens*.

Acknowledgments

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7512

Semiclosed Seawater System With Automatic Salinity, Temperature, and Turbidity Control

SID KORN[1]

ABSTRACT

The new seawater system at the Southwest Fishery Center, Tiburon Laboratory, is described. The system delivers up to 450 l/min of filtered, ultraviolet sterilized, temperature- and salinity-controlled seawater suitable for extended holding of marine fish and invertebrates. Unique aspects of the system including provisions for open and/or closed circulation, and the pneumatic salinity control components are described in detail. The design of this facility may offer ideas to others desiring near-oceanic quality seawater from marginal sources.

INTRODUCTION

The purpose of this paper is to describe the new seawater facility of the National Marine Fisheries Service (NMFS), Southwest Fisheries Center, Tiburon Laboratory. Special emphasis is placed on the salinity control components and design features that allow for either open or closed circulation. I hope this information will assist other facilities with water supplies varying in temperature, salinity, and turbidity, in their effort to obtain near-oceanic quality water.

This facility is located on San Francisco Bay where water conditions vary considerably in temperature, salinity, and turbidity, partially caused by runoff from the Sacramento-San Joaquin rivers. The former seawater system, operating from 1967 to 1971, did not control temperature or salinity and had a limited filtering capacity. Fouling of waterlines and tanks, wide fluctuations in temperature (range 9°-20°C) and salinity (range 2-30‰), and bacterial disease problems made research impossible during certain times of the year. This facility is used for physiological research and needs a system that supplies water of near-oceanic quality with constant physical conditions.

Final specifications and design work were completed by consulting engineers. The system was constructed from November 1972 to April 1973.

The new seawater system (Fig. 1) is a semiclosed system which can circulate 450 l/min of filtered, sterilized, temperature- and salinity-controlled water. Most of the system is duplicated to facilitate repairs and cleaning without disruption of the waterflow.

Due to the high cost of salinity and temperature control, most of the water is recirculated. However, some open circulation is required when toxic effluents from experiments are involved and to insure that problems associated with recirculating water do not occur. After water has been recirculated for extended periods through tanks containing a biomass, nitrates accumulate, trace elements may be lost, and pH may change. Therefore, we always maintain at least 10% of the total flow to open circulation. Toxic effluents are filtered through activated charcoal before being discharged.

FLOW DESCRIPTION

Seawater is pumped by one of two centrifugal pumps (Ace 3 horsepower, hard rubber [Fig. 2]), through a two-stage, automatically backflushing, high-rate sand filter (Baker Model HRB-30). From the filter, the flow is directed to either the sump tank or back into the bay by an electrically actuated valve, which is controlled by a level indicator in the reservoir (Fig. 1). This is done to prevent excess water from entering the system. Dual 3-inch PVC (polyvinyl chloride) lines allow for cleaning of lines and changing of the pump.

The 600-liter epoxy-lined concrete sump tank collects new filtered water and water that has been recirculated through the laboratories. As the water level rises, one of two 10-horsepower centrifugal pumps (Allis Chalmers Model F-4, 316 stainless steel) is activated by a float valve. Water is pumped through a second single-stage sand filter (Baker Model HRB-36) to the 53,000-liter reservoir (Fig. 3). The water enters the reservoir through a redwood splash tray aerator patterned after a similar design at the Southwest Fisheries Center, La Jolla, Calif. (Lasker and Vlymen 1969).

The concrete reservoir is epoxy-lined and is divided by a concrete wall into two sections. Water can be valved to enter and leave one or both sides. This allows for the cleaning of one half of the reservoir without disrupting the flow through the system. The capacity of the tank allows for a 2-h full flow reserve in the event of a failure. By reducing flow rates to 112 l/min this reserve can be extended to 8 h.

Water flows (up to 450 l/min) by gravity from the reservoir to the wet laboratories passing through: an ultraviolet (UV) sterilizer; a heat exchanger; and temperature- and salinity-measuring probes. The flow is then directed into tanks and aquaria as needed (Fig. 4). Depending on the need for open or closed circulation, the effluent line is valved to direct flow into concrete trenches

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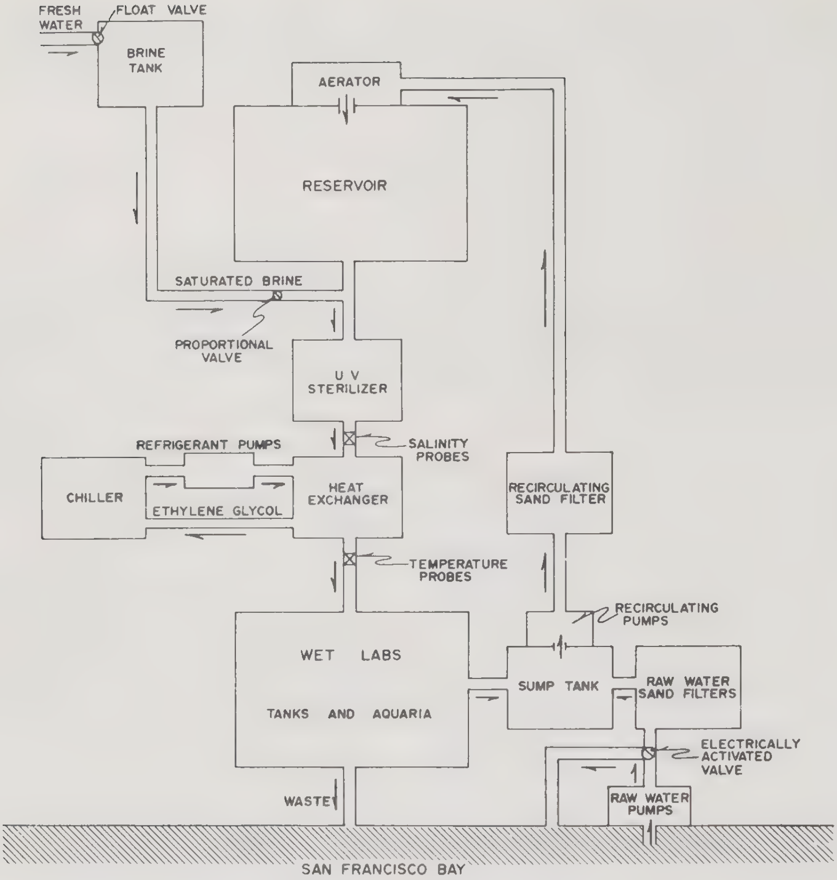
FRESH WATER
FLOAT VALVE
BRINE TANK
AERATOR
RESERVOIR
SATURATED BRINE
PROPORTIONAL VALVE
U V STERILIZER
REFRIGERANT PUMPS
SALINITY PROBES
CHILLER
ETHYLENE GLYCOL
HEAT EXCHANGER
RECIRCULATING SAND FILTER
TEMPERATURE PROBES
RECIRCULATING PUMPS
WET LABS
TANKS AND AQUARIA
SUMP TANK
RAW WATER SAND FILTERS
ELECTRICALLY ACTIVATED VALVE
WASTE
RAW WATER PUMPS
SAN FRANCISCO BAY

Figure 1.—Schematic of Tiburon seawater system.

Figure 2.—Intake pumps, showing cleanouts and dual piping.

Figure 3.—Reservoir, aerator, brine tank, and pneumatic salt delivery line.

Figure 4.—Part of main wet laboratory. Plastic sheeting isolates tanks at rear for behavioral observations.

where it flows out a 6-inch cast iron line into the bay, or into 3-inch PVC recirculating pipes which deliver the water to the sump tank for recirculation (Fig. 5). Three-inch caps on Y fittings are located every few feet to allow entry to the recirculating lines.

All piping and valves in the system are schedule 80-PVC. Piping is in straight runs with threaded caps serving as cleanouts at each end. All seawater lines are dual to allow for maintenance, except for piping downstream from the UV sterilizer, where cleaning is minimal.

TEMPERATURE CONTROL

The seawater can be cooled to a set temperature (± 2° C). Although this temperature can be adjusted for the entire system, investigators must vary temperature in their tanks by individual cooling and heating devices.

A 750,000 BTU (British thermal unit) air-cooled compressor (Trane Model CGAA-6004-MA) cools ethylene glycol, which is circulated by one of two centrifugal pumps (Allis Chalmers Model F2L1, cast iron) through an all glass heat exchanger (Corning Model 600-GRB). An air-operated temperature probe in the seawater effluent line from the heat exchanger controls the compressor through five steps of capacity. At the maximum step of capacity, 450 l/min can be cooled 10°C. The Corning heat exchanger is similar to that described by Lasker and Vlymen (1969).

Figure 5.—Recirculating line in trench. Y fittings serve as entry points.

SALINITY CONTROL

The salinity can be adjusted to any level above ambient (±0.5‰). A 41,600-liter fiber glass brine tank is filled pneumatically with 31,745 kg of rock salt (Fig. 3). This salt is the unrefined product of a salt company located in the San Francisco Bay area. A typical analysis is given below:

Component	*Percent*
Calcium sulfate	0.09
Magnesium chloride	0.03
Magnesium sulfate	0.01
Moisture (H_2O)	3.45
Water Insolubles	0.01
Sodium chloride	96.41

Freshwater enters the tank, controlled by a float valve, and becomes saturated brine solution. This is metered into the seawater line by gravity flow through a stainless steel air-operated proportional valve, controlled by a conductivity meter pneumatic control system (Fig. 6). This system, patterned after Hettler et al. (1971), features conductivity meters with platinum probes mounted in the seawater line, a pneumatic controller, and chart recorder (Fig. 7). The temperature-compensated conductivity signal is converted to salinity, then recorded on a 7-day chart and fed into the pneumatic controller. The salinity is dialed on the controller, the instrument measures the difference between measured salinity and the set point, and sends a variable air pressure (4-15 pounds) to adjust the proportional valve. Variation in the salinity has been controlled to ±0.5‰. By adding another proportional valve connected to a freshwater source, one could lower the salinity if needed.

ALARM SYSTEM

An alarm has been incorporated into this system to avoid loss of fish and research time from component failures (Fig. 7). Specifically, the system alarms if: 1) water temperature exceeds high or low set points; 2) salinity exceeds high or low set points; 3) the water level is too high in sump tank; 4) the water level becomes too low in the reservoir; or 5) the electric power fails. An alarm signal activates a bell and timer. If the alarm persists past a preset time interval (30-300 s), a telephone dialer is activated, sending a signal to a local alarm company that has 24-h service (they have a list of people to call for corrective maintenance).

PERFORMANCE AND MAINTENANCE

The Tiburon Laboratory seawater system has been operating since April 1973. As of October 1974, after some modifications, the system is meeting the objectives of high water quality year-round.

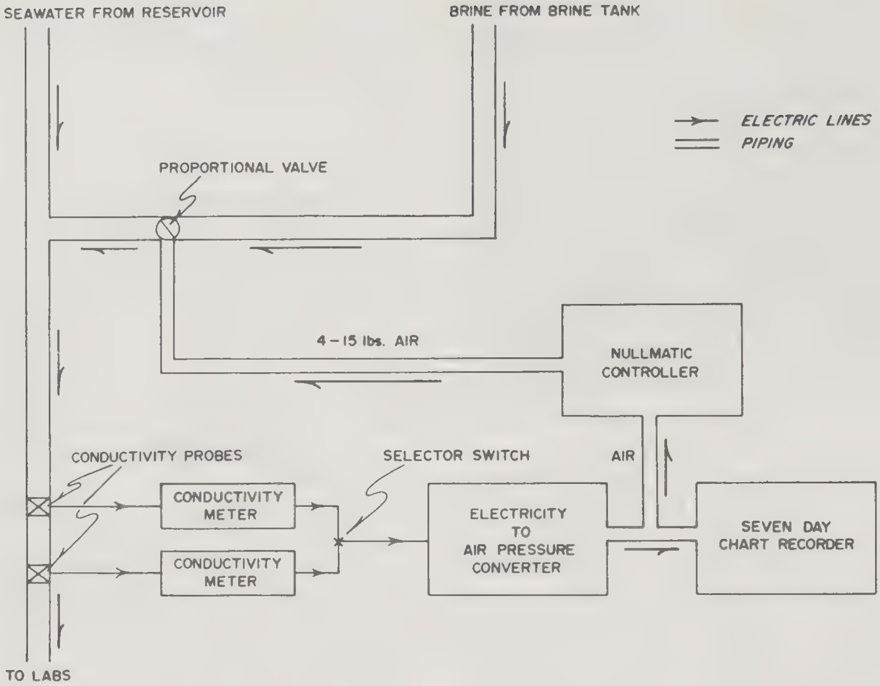
SEAWATER FROM RESERVOIR
BRINE FROM BRINE TANK
ELECTRIC LINES
PIPING
PROPORTIONAL VALVE
4 – 15 lbs. AIR
NULLMATIC CONTROLLER
CONDUCTIVITY PROBES
SELECTOR SWITCH
AIR
CONDUCTIVITY METER
CONDUCTIVITY METER
ELECTRICITY TO AIR PRESSURE CONVERTER
SEVEN DAY CHART RECORDER
TO LABS

Figure 6.—Schematic of salinity control system.

During September-December 1974, two filtered raw water samples and two recirculating water samples (entering the wet laboratories) were taken to determine water quality changes caused by recirculation with changing biomass. Samples were analyzed for nitrate, nitrite, and phosphate by a state-certified water quality laboratory. Temperature, pH, and salinity were measured at this facility (Table 1).

The results show no significant increase in nitrite, phosphate, and pH with recirculated water. Nitrate does accumulate at low levels but adjustment of the open flow will keep nutrients at acceptable levels. The December 9 condition indicates the seawater system water quality at near maximum biomass and flow rates.

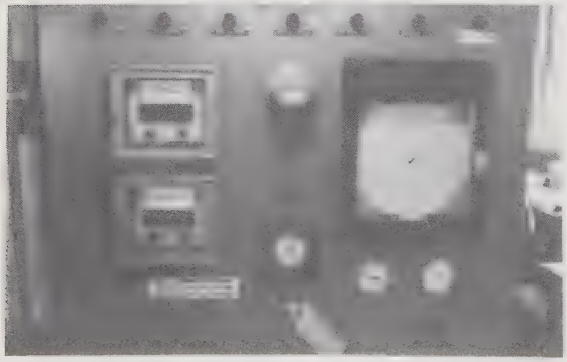

Figure 7.—Control and alarm panel showing alarm indicators (top), conductivity meters (left), nullmatic controller (bottom center), and chart recorder (right).

At this biomass the oxygen content measured in the effluent of the tanks was 1-3 mg/l below saturation. The actual maximum biomass the system will maintain depends on the species held, temperature, and stress factors.

For the past year, although bay turbidities sometimes exceeded 100 Jackson Turbidity Units (JTU, Hach 2100 Turbidometer), values in the laboratories never exceeded 5 JTU. Because of this, cleaning of lines containing filtered water has been unnecessary. The absolute water clarity is important for the efficient functioning of the UV system (Herald et al. 1970).

The built-in UV output meter in our model (Refco Model EP-120, 316 stainless steel) indicates whether the unit needs cleaning or lamp replacement. To date, one cleaning has been needed (20% acetic acid soak for 1 h) and several lamps have needed replacement.

The temperature control has been less than satisfactory and will be modified. The high temperature variation of ±2°C is due to the cycling of the compressor through five stages of capacity to maintain the set temperature. A modification is planned whereby a two-way proportional valve controlled by an air-operated temperature controller will direct the ethylene glycol flow into the heat exchanger or a bypass line. This arrangement should allow for precise temperature control (±0.5°C). Plans also call for addition of heating capacity via a large-capacity water heater in the ethylene glycol line.

Salinity control has been precise (±0.5‰) and has been maintained, although bay salinities varied from 12 to

Table 1.—Comparison of raw and recirculated water in the Tiburon seawater system.[1]

Sample	Salinity (‰)	Temperature (°C)	pH	Total phosphate (mg/l)	Nitrate (mg/l)	Nitrite (mg/l)	Recirculating flow (l/min)	Open flow (l/min)	Biomass (kg)
Sept. 10							300	60	20
Raw	26	18	7.8	0.80	0.44	0.02			
Recirc.	26	16	7.8	0.62	0.70	0.02			
Oct. 29							240	55	30
Raw	27	17	7.8	2.5	0.62	<0.01			
Recirc.	26	17	7.8	2.8	0.61	<0.01			
Nov. 14							320	45	40
Raw	23	13	7.8	0.5	0.31	<0.01			
Recirc.	26	14	7.7	0.6	0.43	<0.01			
Dec. 9							400	200	340
Raw	22	12	7.8	0.6	0.37	<0.01			
Recirc.	24	11	7.8	0.6	0.52	0.02			

[1] Mean values, $N = 2$. Total system volume = 65,000 liters.

30‰. Control can be maintained with up to 150 l/min open flow. With an average bay salinity of 18‰ and open circulation of 75 l/min, a level 10‰ higher can be maintained for $270.00/week (salt cost $30.00/ton, delivered). The cost of salt makes it mandatory to recirculate most of the flow and to monitor open circulation during periods of low bay salinities. It is recognized that the unnatural ionic balance of the salt used to increase salinity could cause problems with sensitive invertebrates or fish larvae, although no problems have been encountered to date.

No maintenance has been required except routine calibration. It is expected that the conductivity probes will need cleaning and replatinization every 2 yr, and the brine tank will need cleaning every 2-3 yr.

This seawater system has allowed us to hold and maintain a wide variety of organisms including adult and larval Pacific herring, adult and larval northern anchovy, juvenile striped bass, juvenile chinook salmon, and other bay fish and invertebrates. Organisms have been held for up to 8 mo and used for determining effects of petroleum components on their physiology. Pacific herring and northern anchovy have been reared from eggs to juveniles. We have achieved our goal of year-round research with near-oceanic quality water.

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7513

FIELD CRITERIA FOR SURVIVAL OF ANCHOVY LARVAE: THE RELATION BETWEEN INSHORE CHLOROPHYLL MAXIMUM LAYERS AND SUCCESSFUL FIRST FEEDING[1]

Reuben Lasker[2]

ABSTRACT

Northern anchovy larvae, *Engraulis mordax*, produced by laboratory-spawned fish, have been used to detect concentrations of larval fish food in situ along the California coast. First-feeding larval anchovies, whose development was controlled by temperature manipulation aboard ship, were placed in samples of Los Angeles Bight water taken from the surface and from chlorophyll maximum layers. Feeding by larvae in water from the surface was minimal in all experiments but extensive feeding occurred in water from the chlorophyll maximum layers when these contained phytoplankters having minimum diameters of approximately 40 μm and which occurred in densities of 20 to 40 particles/ml. In March and April 1974, the chlorophyll maximum layer along the California coast from Malibu to San Onofre (a distance of about 100 km) consisted chiefly of a bloom of the naked dinoflagellate *Gymnodinium splendens*, a food organism known to support growth in anchovy larvae. Copepod nauplii and nonliving particles were never in high enough concentration or of the proper size to be eaten by the larvae. A storm which caused extensive mixing of the top 20 m of water obliterated the chlorophyll maximum layer and effectively destroyed this feeding ground of the larval anchovy.

Probably the major problem confounding fishery scientists interested in rational management of fisheries is an inability to predict recruitment failure (Gulland 1973) despite the vast amount of laboratory and field work on food chain analysis leading to fish production which has occupied many workers in marine studies for the past two decades (Steele 1970). Gulland (1973) asks the most pressing question, "Can a study of stock and recruitment aid management decisions?" and in the same article answers "No." This pessimistic reply is given because, as he says, "there is no method which is likely to be generally successful, [because] the most promising depends on lengthy and costly collection of data, probably extending over a long period." The work reported in this paper suggests an approach which has not been previously used in fishery research as far as I am aware, and which, I believe, makes the answer Gulland has given somewhat less pessimistic than when he made it.

However, it is generally agreed among fishery biologists that large spawning populations of fish do not ensure subsequent large year classes, and conversely, small spawning populations occasionally give rise to exceptionally large classes (Hjort 1926). Hjort (1914) postulated that these variations in year class strength are probably due to differential mortality of the larvae. He believed, for example, that the larvae of the Norwegian herring, *Clupea harengus*, suffered huge mortalities resulting in small year classes when there was a lack of food for the first-feeding larvae. The attractiveness of this hypothesis has generated a number of laboratory studies (see, for example, Lasker et al. 1970) which have shown that the density of larval food must be higher than that usually found at sea in order to obtain even moderate larval growth and survival. For an in-depth discussion of the larval "critical period" as affected by food see May (1974), and for a review of laboratory attempts to rear fish larvae, refer to May (1971). The conclusion that the mean density of larval food organisms in the ocean is generally too low to support reasonable survival of fish larvae through metamorphosis, is also substantiated by data from field surveys (Beers and Stewart 1967, 1969). Thus, despite extensive efforts in quantitative marine food chain analysis, it is yet to be demonstrated whether, where, and to what extent there are rich feeding areas in the sea for larval fishes.

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As a new approach to this problem it is the purpose of this study to show how laboratory-spawned fish larvae can be used to detect larval feeding grounds at sea and to point out some of the ways this technique might be used to provide the link between marine food chain research and stock and recruitment predictions in fisheries; the latter by determining what the environmental conditions at sea must be with respect to larval fish food to result in a good or bad survival year for particular species of fish larvae.

Because it is essential to the general methodology of using larval fishes as assay organisms for the fitness of seawater as larval fish feeding grounds, in the following I describe some background information on maturation and spawning of anchovies in the laboratory; the methods used for feeding larval anchovies; and the laboratory-determined criteria for feeding already known for the larva of this species. A description of the field work is then given, concluding with a discussion of the criteria which can be used to judge the fitness of the larval anchovy's environment.

THE NORTHERN ANCHOVY

In the California Current, the major pelagic fish population at present is that of the clupeoid *Engraulis mordax*, the northern anchovy. This species is found from British Columbia, Canada to Cape San Lucas, Baja California and extending west about 600 km. Although the anchovy has a protracted spawning season from December to August, about three-quarters of its spawning occurs in the winter and spring months of January, February, March, and April. The factors affecting larval mortality of clupeoids have been investigated in a number of laboratories throughout the world (Holliday and Blaxter 1963) including my own. Recently, it has been possible to intensify laboratory research at the Southwest Fisheries Center La Jolla Laboratory, National Marine Fisheries Service because of the continuous availability of anchovy larvae. This has been made possible by inducing sexual maturation of adults in the laboratory resulting in daily spawning and fertilization of anchovy eggs throughout the year. Details of this maturation and spawning technique are given by Leong (1971) and Lasker (in press). The availability of first-feeding larvae hatched from laboratory-spawned eggs has made possible the development of a technique whereby specific areas of the ocean could be examined for their potential as larval feeding grounds, and criteria established to characterize parts of the ocean as good or bad areas for larval survival.

LABORATORY-DETERMINED CRITERIA FOR SUCCESSFUL LARVAL ANCHOVY FEEDING

A background of information on larval anchovy feeding is available from a number of studies and was used to guide this investigation.

1. *Particle size at first feeding appears to be critical.* First-feeding anchovy larvae (standard length 3.5 mm) have small mouths and require a food particle about 50 μm in diameter, although particles larger than 100 μm may be taken (Berner 1959). Smaller particles may not be visible to the larvae. Berner (1959) reported that anchovy larvae smaller than 4 mm long taken in plankton tows had eaten particles ranging in length from 24 to 186 μm. However, over 70% of the food in their intestines was between 60 and 80 μm long.
2. *The number of particles per unit volume in the anchovy larva's environment must be above a minimum concentration.* O'Connell and Raymond (1970), using natural plankton as food, showed that the survival of first-feeding anchovy larvae was dependent, in their experiments, on the number of micronauplii per unit volume available to the larvae. Successful first feeding, as pointed out by Hunter (1972), also depends on a sufficiently high density of food particles to compensate for the low capture efficiency (about 10%) exhibited by anchovy larvae when they begin to feed.
3. *The kind of food organism determines survival and growth.* Lasker et al. (1970) fed a variety of phytoplankters and zooplankters to first-feeding anchovy larvae. Only one phytoplankter of those tested, *Gymnodinium splendens*, supported growth and gave relatively good results in survival experiments when compared with larvae fed natural plankton. The rotifer *Brachionus plicatilis*, although not found in the anchovy's normal habitat, also could be used as a laboratory food for older anchovy larvae and a small proportion of first-feeding larvae (Theilacker and McMaster 1971; Hunter 1972).
4. *The greater the concentration of food particles, the more frequent are the feeding strikes made by anchovy larvae; consequently the greater the success in capturing food.* Although examination of field-caught anchovy larvae reveal very few with

any food in their intestine (Arthur 1956; Berner 1959), this seems to be a result of rough handling due to capture in a plankton net and subsequent preservation with Formalin[3] which causes almost all anchovy larvae to defecate (Kjelson et al. 1975). In the laboratory a high proportion of anchovy larvae which had never seen a food particle will strike at and ingest them provided there is a high enough concentration of the right size food particles. Hunter and Thomas (1974) have shown that the rate of larval anchovy feeding increases with increasing food density.

Despite the success of O'Connell and Raymond (1970) and Kramer and Zweifel (1970) who were able to rear anchovy larvae using micronauplii concentrated in wild plankton samples, the quantities needed by the larvae seemed inordinately higher than the concentration of nauplii reported by Beers and Stewart (1967) for the euphotic zone of the California Current. It was possible, of course, that concentrations of nauplii exist in dense aggregations. Beers and Stewart (1970a) reported that nauplii concentrate in or immediately above chlorophyll maximum layers off the California coast. However, no concentrations have been identified which are high enough to support anchovy larvae (e.g., 1/ml). On the other hand, Lasker et al. (1970) showed that anchovy larvae would feed and grow on a diet of the dinoflagellate *G. splendens*. The fact that blooms of a variety of phytoplankters are known to occur in the California Current, particularly in the spring, suggested that phytoplankton cells were more likely to provide the particle size and cell density essential to survival and growth of first-feeding anchovy larvae. For these reasons, inshore chlorophyll maximum layers were selected as possible fruitful areas to investigate for larval feeding.

METHODS

To determine areas in the sea where high concentrations of living particles might be present, a pump was used to bring water on board from known depths. The hose from the pump was lowered below the surface by means of a metered winch. The water was pumped through a Turner fluorometer in the ship's laboratory to measure chlorophyll *a* and other fluorescing substances. Chlorophyll *a* was extracted from water samples taken at each station from different depths and the fluorescence profile adjusted to reflect only chlorophyll *a* (Kiefer and Lasker 1975).

A school of approximately 700 sexually mature northern anchovies, maintained in the aquarium of the Southwest Fisheries Center, La Jolla Laboratory, produce about 1,000 fertilized eggs per day. The number of eggs can be increased by injections of gonadotrophins to stimulate massive spawning in individual fish (Leong 1971). With temperature control of development (Lasker 1964), larvae in first-feeding condition can be made available whenever desired. Thus, preliminary to a cruise, development of embryos and larvae can be accelerated or retarded by temperature manipulation to ensure that on each day of the cruise there will be at least several hundred larvae ready to feed.

Prior to each of the cruises described here, fertilized eggs at the same stage of development were sorted into liter jars containing seawater previously filtered through a 5-μm pore size Cuno Aquapure filter, and the jars were immersed in water baths at suitable temperatures. For transport to the ship insulated chests were used, and on board a temperature-controlled room was continually adjusted between 13° and 18°C to insure that feeding larvae would be available on specific days. Recent studies have shown that newly feeding larvae have only about 2½ days after the yolk sac is absorbed to get sufficient food or they will die (Lasker et al. 1970).

Experiments to determine if samples of seawater contained suitable food for anchovy larvae were done in cylindrical, 8-liter jars wrapped with dull black cardboard and set on black plastic. Above the jars a bank of four "daylight" fluorescent lights were suspended which illuminated the surface of the jars at approximately 2,152 lux. When a sample of seawater was brought into the ship's laboratory it was permitted to warm slowly to room temperature. Larvae were added to 5 liters of seawater by pouring them from the incubation jars. Dilution of the 5 liters by the larval incubation water was corrected by concentrating the contents of an additional liter of seawater to a few milliliters with fine mesh netting and by adding the concentrate to the whole.

A gentle air stream was directed onto the surface of the water in each experimental vessel to ensure mixing of the water. Control experiments on shipboard with cultured organisms indicated that this had little effect on the larvae.

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[3] Reference to trade names does not imply endorsement by the National Marine Fisheries Service, NOAA.

Two cultured food organisms, *G. splendens* and *B. plicatilis*, were used aboard ship to determine if any particular batch of test larvae was in good condition and would feed. Details on the culture of these organisms are given by Thomas et al. (1973) for *G. splendens*, and Theilacker and McMaster (1971) for *B. plicatilis*. Usually a control 5-liter seawater sample was seeded with one or the other cultured organism and a feeding experiment with larvae run concurrently with samples of natural seawater.

Larvae were permitted to feed for 8 h then siphoned out and sucked down onto a membrane filter (pore size 0.8 μm) using a vacuum pump. This rapid removal of larvae from the experimental containers and their fast immobilization on the filters prevented defecation. After air drying, microscopic examination of the transparent larvae permitted counts to be made of larvae which had been feeding and those which had not. The relative proportion of feeding to nonfeeding larvae was subsequently correlated with sizes of the food particles, chlorophyll content, species composition, and the number of particles available to the larvae.

A 1-liter subsample of each seawater sample was preserved with Formalin (final concentration 5%) (Beers and Stewart 1970b). Later the particles in the preserved seawater were settled out and the species enumerated. The method of Utermöhl (as described by Lund et al. 1958) was used to concentrate organisms from known volumes of preserved seawater, usually 100 ml. At least 100 cells larger than 20 μm in diameter were counted from each settled water sample.

On a cruise of the NOAA RV *David Starr Jordan*, 18-21 March 1974, a 16-channel electronic particle counter with a 280-μm pore, Coulter Counter Model Ta, was used to determine the size distribution and numbers of sized particles in seawater samples used for feeding experiments. Only particles 20 μm and larger were counted. Very good agreement was obtained between the electronic counter particle counts and those obtained with the inverted microscope. A comparison is shown in Figure 1. The speed of counting and sizing particles makes the multichannel particle sizing instrument desirable for rapid field assessment of larval fish food organisms. Because the electronic counter was unavailable for two subsequent cruises. 8-12 and 22-23 April 1974, the results for these are given from microscope counts only.

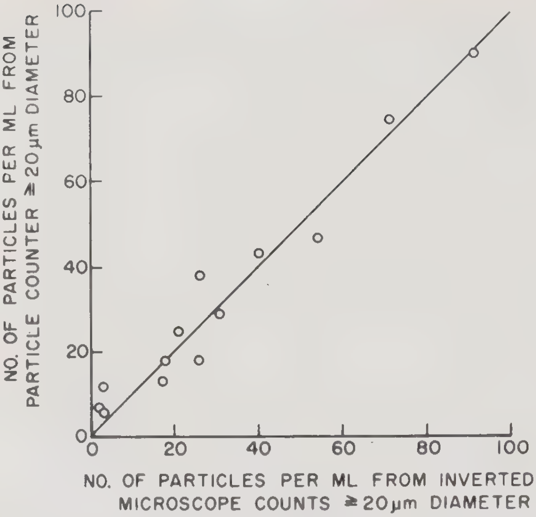

FIGURE 1.–Comparison between instantaneous particle counts per milliliter taken with Model Ta Coulter Counter and mean particle count per milliliter observed through an inverted microscope. A 100-ml sample was concentrated and at least 100 particles of the dominant organism were counted in any visual field. Only particles larger than 20 μm were counted.

To ascertain if anchovy larvae were present at particular depths, plankton tows were taken with a 0.333-mm mesh, 0.5-m mouth diameter net. Because an opening and closing net was unavailable for this work, an open net was dropped rapidly to the desired depth, towed for 10 min at a maintained wire angle of 45°, then pulled up rapidly. The total proportion of time the net spent in water other than in the desired stratum never exceeded 5% of the total towing time. All larvae captured were measured, sorted to species, and counted. Larval counts were corrected to a comparative volume of 1,000 m^3 (Kramer et al. 1972). A flowmeter in the mouth of the net provided a record of the volume of water filtered.

The shipboard experiments were ordinariy done at temperatures of between 15° and 19°C, whereas concentrations of larval fish food organisms and anchovy larvae were occasionally found between 14° and 15°C. It was desirable, therefore, to determine the feeding response of first-feeding anchovy larvae at different environmental temperatures. Experiments to determine this were identical to those done at sea except that the concentration of the cultured organism *G. splendens* was varied from 5 to 200 cells/ml, and the water temperature was controlled within ±0.2°C.

AREA OF STUDY

This investigation was conducted in the Los Angeles Bight along the southern California coastline from Malibu to San Onofre, between 18 and 21 March 1974. All the stations occupied were over the 20-fathom line except for the Laguna Beach station which was over the 270-fathom contour. Table 1 gives the coordinate positions and Figure 2 shows the relative location of the stations. The San Onofre station was reoccupied on 8 April 1974 to determine the persistence of the chlorophyll maximum layer which earlier had contained relatively large numbers of *G. splendens*. The station was occupied again on 10 April, after a violent wind storm and later on 22-23 April after a period of no storms.

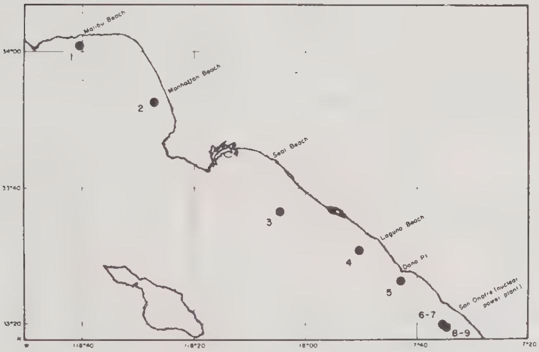

FIGURE 2.–Stations in the Los Angeles Bight.

RESULTS AND DISCUSSION

Shipboard Experiments with First-Feeding Anchovy Larvae

Table 1 provides a summary of the results of feeding experiments with first-feeding anchovy larvae in water from the surface and from the chlorophyll maximum layer or from a depth of about 15 m if no clear chlorophyll maximum was observed. The dominant phytoplankter in the chlorophyll maximum layers was *G. splendens*. For details about *G. splendens* blooms from Baja California, Mexico, and the Los Angeles Bight see Kiefer and Lasker (1975); as reported earlier, Lasker et al. (1970) had demonstrated that anchovy larvae will grow when fed on *G. splendens*.

Also given in Table 1 are the results of a feeding experiment at the San Onofre station on 8 April 1974, 18 days after a chlorophyll maximum layer containing *G. splendens* as the dominant phytoplankter was found. The chlorophyll maximum layer was still present and heavily populated with *G. splendens*. A violent wind storm on 9 April obliterated the chlorophyll maximum layer and no *G. splendens* were seen at this station when it was reoccupied on 10 and 11 April. A comparison of chlorophyll *a* profiles taken before and after the 9 April storm is shown in Figure 3. The results of control feeding experiments are given in Table 2.

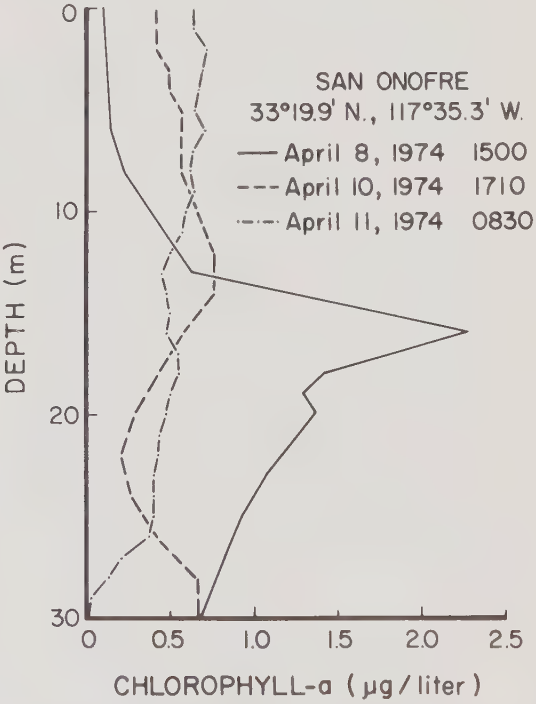

FIGURE 3.–Chlorophyll maximum layers before (8 April 1974) and after (10 and 11 April 1974) a violent wind storm near San Onofre, Calif.

Some anchovy larvae capture a few particles in any concentration of 20- to 100-μm particles over an 8-h period, but experience in the laboratory has shown that feeding on less than 1 particle/h will not sustain a first-feeding larva which becomes weak and dies. Thus, in Tables 1 and 2, two feeding categories are indicated: larvae observed with food organisms packed into the intestine, and

TABLE 1.–Summary of results of 8-h on-board feeding experiments with first-feeding anchovy larvae. *Gymnodinium splendens* appeared in the chlorophyll maximum layers (chl. max.) from Malibu to San Onofre, a distance of approximately 130 km. The subsurface bloom of *G. splendens* at San Onofre persisted until 8 April 1974 (see no. 7 below). A storm on 9 April obliterated the maximum and evidently dispersed the *G. splendens* by wind mixing (see Figure 3).

No.	Date and time A. Surf. temp. B. Chl. max., temp. and depth	Position (lat. N-long. W)	Total number particles/ml		μg Chl. *a* per liter	Feeding by anchovy larvae		
						Percent of larvae with:		Number of larvae per experiment
			23-37 μm diameter	>37-299 μm diameter		¼ to full gut	1-8 particles in gut	
1	20 March 1974, 1250							
	A. 15°C	34°00.8′-118°40.6′	14.2	[1]4.1 (< 1)	[2]1.0	2	15	69
	B. 14.2°C, 12 m	(Malibu)	37.3	38.0 (12)	1.8	23	46	93
2	20 March 1974, 1745							
	A. 15.2°C	33°52.5′-118°27.0′	23.1	6.1 (6)	0.4	0	11	94
	B. 14.5°C, 13.5 m	(Manhattan Beach)	29.8	19.7 (12)	1.3	0	18	49
3	21 March 1974, 0900							
	A. 15.8°C	33°36.5′-118°04.3′	217.9	33.2 (<1)	0.3	0	12	42
	B. 14.2°C, 16.5 m	(Seal Beach)	53.8	352.0 (380)	42.0	22	24	104
4	21 March 1974, 1340							
	A. -	33°30.8′-117°50.3′	34.0	9.0 (0)	0.6	0	10	20
	B. -, 15 m (no chl. max.)	(Laguna Beach)	29.0	5.7 (0)	0.7	0	11	46
5	21 March 1974, 1715							
	A. 15.5°C	33°26.3′-117°42.8′	18.7	5.9 (<1)	0.5	[3]5	16	19
	B. -, 15 m	(Dana Point)	55.2	23.2 (5)	1.3	0	69	26
6	21 March 1974, 1900							
	A. 15.2°C	33°19.9′-117°35.3′	9.3	4.0 (<1)	0.2	0	8	49
	B. -, 19.5 m	(San Onofre)	42.4	47.7 (34)	2.3	9	25	32
7	8 April 1974, 1500							
	A. 17.1°C	33°19.9′-117°35.3′	5.7	9.1 (<1)	0.2	0	13	23
	B. 14.8°C, 16 m	(San Onofre)	14.0	81.3 (64)	2.3	9	40	58
8	10 April 1974, 1710							
	A. 14°C	33°19.4′-117°34.6′	8.4	14.1 (0)	—	0	12	33
	B. 13.5°C, 14 m (no chl. max.)	(San Onofre)	10.5	23.2 (0)	0.8	0	15	20
9	11 April 1974, 0915							
	A. 13.0°C, 5 m (no chl. max.)	33°19.5′-117°34.6′ (San Onofre)	6.4	10.5 (0)	0.6	0	4	50

[1] ( ) = number of *G. splendens* per milliliter.
[2] Particles smaller than 20 μm may have contributed to the elevated chlorophyll *a* at this station.
[3] This 5% figure represents only one larva which filled its intestine ¼ full.

TABLE 2.–Controls for the experiments reported in Table 1. Surface water was seeded with *Gymnodinium splendens* or *Brachionus plicatilis*. In each instance the results showed that the larvae on shipboard were competent to feed. Feeding time was 8 h.

Date	Species seeded	Number particles/ml	Feeding by anchovy larvae		
			Percent of larvae with:		Number of larvae per experiment
			¼ to full gut	1-8 particles in gut	
20 March 1974	*B. plicatilis*	40	29	45	72
8 April 1974	*G. splendens*	100	27	13	30
10 April 1974	*G. splendens*	100	32	22	46

those with eight or fewer particles in the intestine after an 8-h feeding period. The largest proportion of larvae did not feed at all, a result common to laboratory experiments as well. The feeding intensity at Malibu, Seal Beach, and San Onofre is typical of first-feeding anchovy larvae in laboratory experiments seeded with a like number of suitable size particles, e.g., *G. splendens*.

The data presented in Table 1 show that the criteria for larval anchovy feeding determined by laboratory experiments are the same when freshly obtained seawater is tested as a source of larval anchovy food. Large numbers of particles smaller than 37 μm in diameter did not stimulate feeding in anchovy larvae. This was particularly apparent at Seal Beach on 21 March; surface water having 218 particles/ml smaller than 37 μm in diameter but with low chlorophyll *a* did not stimulate anchovy larvae to feed. Conversely, the bloom of *G. splendens* in the chlorophyll maximum layer produced heavy feeding larvae tested in shipboard experiments. Furthermore, even with particles having the right diameter for feeding, a minimum concentration of perhaps between 25 and 50 cells/ml was needed.

The Effect of Temperature on Feeding

The chlorophyll maximum layers along the coast were characterized by temperatures between 14° and 15°C, which is lower than the optimum temperature for feeding and growth in anchovy larvae (16°C). Because shipboard experiments were done at temperatures higher than those found in the chlorophyll maximum layers it was desirable to determine if the minimum particle count at which first-feeding larvae were stimulated to feed was in any way reduced by lower temperatures. Figure 4 illustrates the results of experiments which show that at 14°C, the food particle count must be higher than 20 cells/ml before significant feeding can occur over an 8-h period. At the higher temperature tested, 18°-19°C, food particle counts of between 5 and 20 particles/ml may stimulate feeding. However, during the shipboard experiments, particle counts of 5-20 cells/ml did not stimulate larval feeding even at the higher temperatures (15°-19°C) of the ship's laboratory (Table 1). This discrepancy may be due to the different kinds of food particles available to the larvae, as well as to other factors related to a larva's inability to capture certain particles as opposed to others. For example, when *Chaetoceros* sp. was present in any of the samples, anchovy larvae did not feed on this phytoplankter, owing probably to the spiny nature of this chain-forming diatom, despite the considerable lengths (longer than 37 μm) of the chains. In the Seal Beach surface sample taken on 21 March 1974, *Chaetoceros* sp. and other chain-forming diatoms made up over 30% of the longer than 37-μm category. This result was confirmed at a station off Imperial Beach, Calif. (lat. 32°34.0′ N; long. 117°10.5′ W) on 11 April where a dense bloom dominated by *Thalassiosira* sp. (37 chains/ml) was found. Chlorophyll *a* at the surface was 4.8 μg/liter and slightly higher, 5.1 μg/liter, at a depth of 7 m. Feeding by anchovy larvae on this organism was virtually nil. Thus, the composition of the stock of phytoplankton appears to be an important factor in the initial feeding of anchovy larvae.

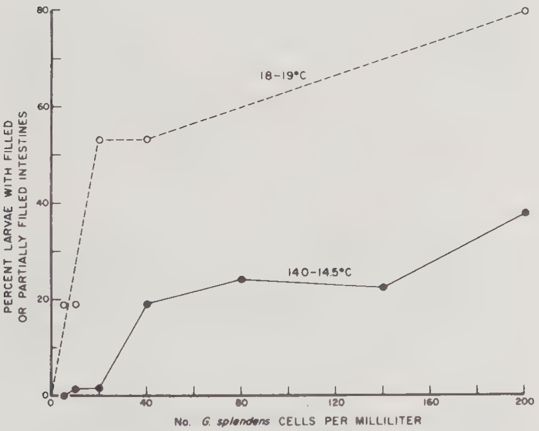

FIGURE 4.—The effect on larval anchovy feeding of different concentrations of food at two temperatures. Each experiment began with 100 larval anchovies which were in first-feeding condition and was terminated after 8 h. See text for details.

The observations described above indicate that chlorophyll measurements alone, and the indication of a strong chlorophyll maximum layer are not by themselves sufficient criteria for establishing the existence of good conditions for the feeding of anchovy larvae. A cruise of the RV *David Starr Jordan* was made back to the San Onofre station on 22 and 23 April 1974. A sharp chlorophyll maximum layer was discovered there once again and was found to extend seaward for at least 14 km (Figure 5), yet shipboard larval anchovy feeding was negative. Subsequent microscopic examination of the water from these layers indicated that cryptomonads of about 10 μm in diameter dominated the samples in concentrations of 3,400-7,200 cells/ml, a size too small to be fed upon by anchovy larvae.

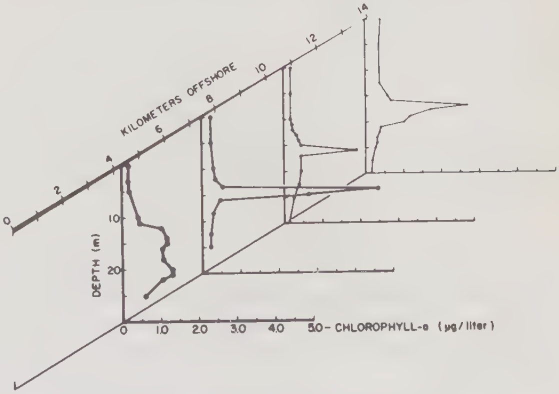

FIGURE 5.—Chlorophyll maximum layers off San Onofre, Calif., 22-23 April 1974.

Vertical Distribution of Anchovy Larvae

At San Onofre on 8 April the chlorophyll maximum layer was due, in part, to a high density of *G. splendens*. Larvae on board ship fed freely in the water from this layer. Judging from the larval feeding and the size and density of the food particles, this chlorophyll maximum layer should have been an ideal place for first-feeding larvae to be found. To test this, plankton tows were made at three depths: within the chlorophyll maximum layer at 16 m, just above the layer at 10 m, and at the surface (see Figure 3). The standard length of anchovy larvae from these tows was measured, and the degree of eye pigmentation noted (full pigmentation indicating a visually competent larva). The results, given in Table 3, show that there was a distinct difference in vertical distribution between the number of first-feeding larvae that could see as opposed to yolk-sac larvae which lack eye pigmentation and could not see.

The surface water contained 2,100 anchovy larve/1,000 m^3. Larvae without eye pigmentation outnumbered sighted larvae two to one. At the 10-m stratum above the chlorophyll maximum layer there were 40,000 anchovy larvae/1,000 m^3 with larvae capable of seeing outnumbered by eight to one. In the chlorophyll maximum layer 4,900 anchovy larvae/1,000 m^3 were present but larvae that could see were about as numerous as those which could not. Although it may be coincidental, the possibility that larvae were actively seeking out areas with food cannot be dismissed.

TABLE 3.–Distribution of anchovy eggs and larvae at three depths off San Onofre, Calif., 8 April 1974.

	Number of eggs or larvae per 1,000 m^3		
Stratum	Larvae with pigmented eyes	Larvae with unpigmented eyes	Eggs
Surface	756	1,344	67,200
10 m	4,610	35,804	151,965
16 m	2,004	2,941	60,034

Criteria for Successful First-Feeding by Anchovy Larvae

It is evident from the data presented in this report that the following environmental criteria must be met before first-feeding anchovy larvae can feed successfully in the ocean. Phytoplankton aggregations with over 20 cells/ml must be available at the same time or within 2½ days after the larvae are ready to feed. Individual phytoplankton cells must be about 40 μm in diameter. Successful feeding is dependent on food density so that the higher the concentration of cells, the better the feeding. Monotypic algal blooms are responsible for some chlorophyll maximum layers off the California coast and first-feeding anchovy larvae were found to be living within them. Only some phytoplankters stimulate feeding and support growth of anchovy larvae; for example *G. splendens* is known to support growth while anchovy larvae would not feed on *Chaetoceros* sp. or *Thalassiosira* sp., spiny and/or chain-forming diatoms. Finally, it could not be demonstrated that micronauplii or other microzooplankton contribute significantly to larval anchovy survival during the first week of larval life. Beers and Stewart (1967) reported that in December 1965, the inshore station off San Diego (their station I) contained a maximum of only 30 organisms/liter in the 35 to 103-μm size class. Of these organisms, copepod nauplii and post-nauplii together numbered 7-9/liter, two orders of magnitude lower than that required by anchovy larvae to survive, i.e., 1,000/liter (O'Connell and Raymond 1970). However, it is reasonable to assume that under special circumstances suitable concentrations of micronauplii might serve as a food source for first-feeding anchovy larvae. Nonliving particles larger than 37 μm were not seen and may be insignificant in the nutrition of first-feeding anchovy larvae because of their low concentration in anchovy spawning areas.

It is important to emphasize the transient nature of good feeding conditions. There was a large number of larvae present at depth at the San Onofre station on 8 April 1974, capable of taking advantage of the subsurface bloom of *Gymnodinium*. Furthermore, spawning had been extensive in the entire water column as indicated by the large number of anchovy eggs caught during the same tows (Table 3). Earlier I indicated that a wind storm obliterated the chlorophyll maximum layer at San Onofre on 9 April 1974, and that 8-h shipboard experiments showed the larvae were unable to capture enough food on 10 and 11 April to fill or partially fill their intestines. If my contention is correct, then a large proportion of the larvae which were present as eggs or yolk-sac larvae on 8 April were doomed to die from lack of food after the storm on 9 April because of the dilution and dispersion of suitable larval food organisms.

Although this investigation was confined to first-feeding anchovy larvae, the technique described here, using laboratory-reared larvae for field tests of possible larval feeding areas, probably can be extended to older larvae and other species as well. An on-board electronic counter can give a rapid first evaluation of particle size and cell numbers. Microscopic examination of subsamples can be used to verify the shipboard counts and give additional information on species composition of phytoplankters. Chlorophyll profiles can be analyzed routinely on most oceanographic vessels. With information on the biology of the larvae being investigated, it may be possible to determine routinely the quality and extent of larval feeding grounds and with comprehensive temporal information on the food of the larvae, the degree of larval mortality due to inadequate food may be predictable.

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MFR PAPER 1166

A Uniform U.S. West Coast Logbook for Albacore, *Thunnus alalunga* (Bonnaterre), and Coastwide Albacore Fishery Data System

R. MICHAEL LAURS, CHARLES HOOKER, LARRY HREHA, and RICHARD LINCOLN

Adequate catch and effort statistics are required to evaluate the effects of harvesting and environmental factors on exploited fish populations for it is only through the understanding of such relationships that the aims of fishery research and management can be fully realized. A uniform U.S. West Coast Albacore Logbook was adopted in 1973 to improve the system for collecting catch and effort information for the U.S. fishery on albacore tuna, *Thunnus alalunga* (Bonnaterre). The purpose of this paper is to describe the design of the logbook, the system for handling the logbook data on a U.S. Pacific coastwide basis, and the dissemination of albacore catch information to cooperating fishermen in return for keeping logbook records.

The new uniform U.S. West Coast Albacore Logbook is intended to simplify record-keeping for the fishermen by making necessary only one logbook for the entire U.S. albacore fishery with a format that is efficient and easy to use. Also, it is designed to obtain more complete information on the U.S. albacore fishery and to provide a common system of record-keeping among the States so that information obtained can be more readily processed and made available to fishermen and resource managers.

A voluntary albacore tuna logbook has been issued by the California Department of Fish and Game since 1954 (Craig, 1963) to California albacore fishermen, and by the Fish Commission of Oregon since 1967 to Oregon albacore fishermen. Prior to using logbooks, both states collected catch locality and fishing effort information by interviewing fishermen engaged in albacore fishing. Fishermen interviews were continued by the States after the States adopted logbooks and are being continued in conjunction with the new ones to obtain information from fishermen who did not keep logbooks. Until 1973, there was no logbook or formal interview system for collecting catch and effort information for the Washington albacore fishery. However, boats fishing out of Washington ports often kept logbooks issued by Oregon and California.

Since the mid-1950's, fisheries scientists have recognized the desirability of adopting a uniform coastwide logbook and data system for the albacore tuna fishery, and representatives of state and federal agencies have developed tentative formats for them. Added impetus for this cooperative effort was provided in 1973 as a result of American Fishermen's Research Foundation's active involvement in albacore research, using fisherman-generated funds derived from a self-imposed tax on albacore landings. This program also stimulated funding by NOAA's Sea Grant Program of a 3-year coordinated project in albacore studies via the Pacific Marine Fisheries Commission. This project materially facilitated completion of the uniform logbook and data system, and provided limited funding for additional field personnel to aid in their implementation.

DESIGN OF THE LOGBOOK

The design of the logbook resulted from the cooperative efforts of fishery scientists of the National Marine Fisheries Service (NMFS), California Department of Fish and Game, Fish Commission of Oregon, Washington Department of Fisheries, Pacific Marine Fisheries Commission, and members of the albacore fishing industry.

The logbook measures 8½ × 11 inches, and contains sufficient log sheets for 36 weeks. It is bound by a plastic spiral so that the pages can be folded back enabling the logbook to be hung on the bulkhead if desired. Heavy-gauge paper stock is used for the cover (Fig. 1) and fold-out flap,

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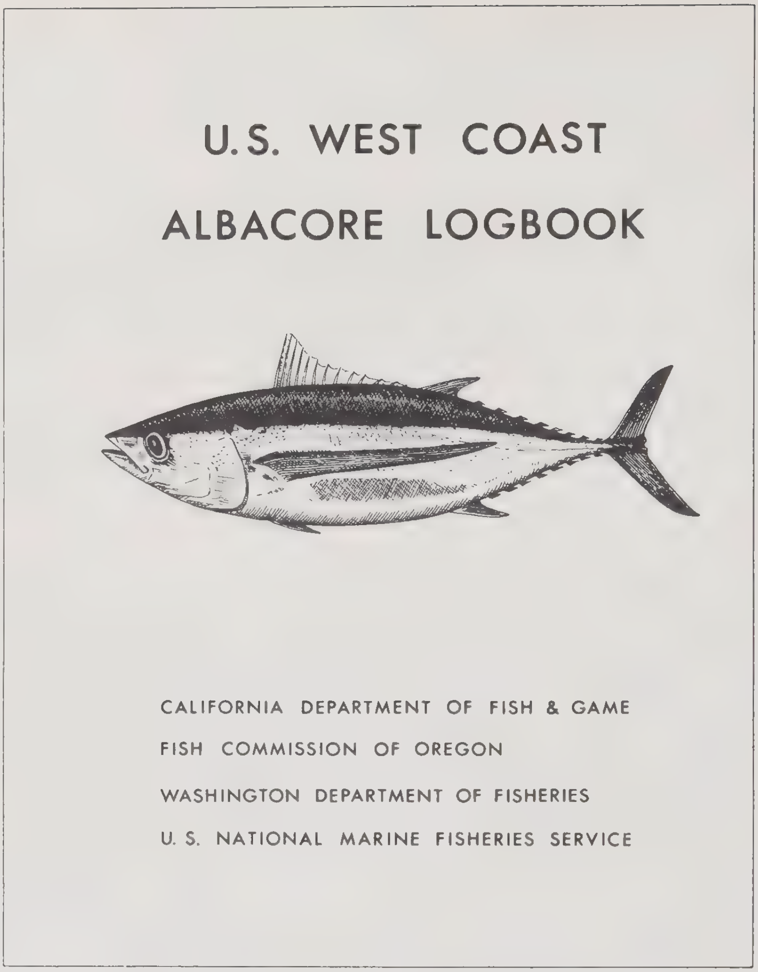
and National Cash Register (NCR)[1] "carbonless" paper is used for the logbook sheets. Instructions for using the logbook are printed on the fold-out flap which is inserted under the "carbon" of the NCR paper to prevent carry through. The inside of the cover contains information on what to do in the event that a tagged fish is caught (Fig. 2), and on the inside of the back cover is a length-weight table for albacore.

The logbook is divided into two portions: 1) an albacore fishing operations information sheet; and 2) fishing log sheets for keeping daily records. The fishing operations information section (Fig. 3) provides data on the composition and characteristics of the albacore fishing fleet so that changes in fleet efficiency may be evaluated and the summarized logbook data may be more readily standardized from year to year. Fishermen are requested to provide information on the size, speed, and hold capacity of the vessel, navigation, radio, and special equipment, refrigeration type, crew size, and crew fishing experience.

The fishing log sheets (Fig. 4) consist of daily entries divided into necessary information, desired information, and remarks. Fishermen are requested as a minimum to fill out the necessary information category and are encouraged to also complete the desired information category and record pertinent remarks. The necessary information category includes data essential for the calculation of catch per unit of effort including catch localities, amount of catch, amount of fishing effort, and type of fishing gear used. The desired information category includes data which are useful in evaluating catch per unit of effort statistics and in studies involving catch per unit information derived from the logbook records. The desired information includes an estimate of the amount of fish in the area fished, estimated weight of fish caught, sea surface temperature, wind conditions, and sea conditions.

Under remarks fishermen are requested to record observations that may be of interest such as movement of fish, type of feed, temperature "edges" or "fronts," water color, bird flocks, etc.



U.S. WEST COAST

ALBACORE LOGBOOK

CALIFORNIA DEPARTMENT OF FISH & GAME

FISH COMMISSION OF OREGON

WASHINGTON DEPARTMENT OF FISHERIES

U. S. NATIONAL MARINE FISHERIES SERVICE

Figure 1.—Cover of uniform U.S. West Coast Albacore Logbook.

DISTRIBUTION OF LOGBOOKS AND COLLECTION OF LOGBOOK RECORDS

The logbook is distributed to albacore fishermen by an albacore fishermen's association, the state fisheries agencies, and NMFS. Each year, the Western Fishboat Owners Association mails a logbook and a letter endorsing the use of the logbook to its approximately 625 members representing about 70 percent of the tonnage capacity of the U.S. albacore fleet. Fishery technicians from the California, Oregon, and Washington State fisheries agencies canvass the waterfront prior to the start of the albacore fishing season and distribute logbooks to vessels that do not have them. A small number of logbooks are mailed by NMFS to fishermen requesting them.

Most of the logbook records are collected by State fishery technicians who visit the waterfront regularly during the fishing season while the boats are unloading. The technicians also obtain catch and effort information by interviewing fishermen who did not keep a logbook.[2] About 20 percent of

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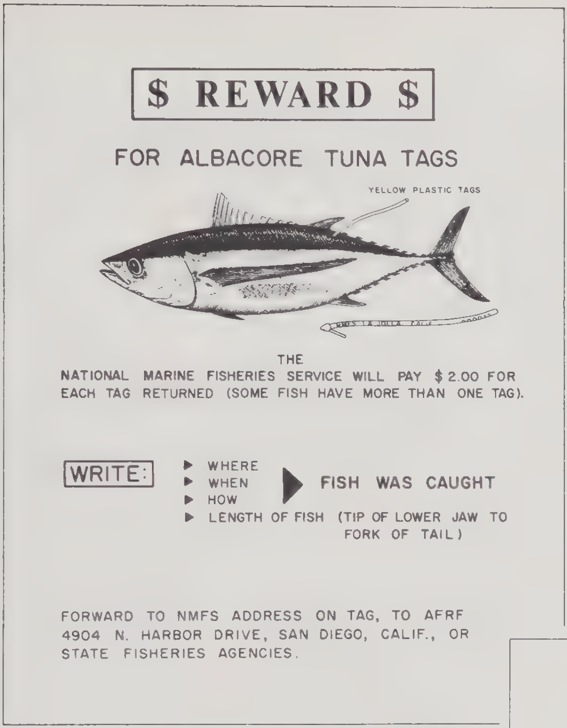
[1] Reference to trade names does not imply endorsement by the National Marine Fisheries Service, NOAA.

[2] In addition, the technicians measure the fork length of samples of fish from catches.



$ REWARD $

FOR ALBACORE TUNA TAGS

YELLOW PLASTIC TAGS

THE
NATIONAL MARINE FISHERIES SERVICE WILL PAY $ 2.00 FOR EACH TAG RETURNED (SOME FISH HAVE MORE THAN ONE TAG).

WRITE:

- WHERE
- WHEN
- HOW

FISH WAS CAUGHT

- LENGTH OF FISH (TIP OF LOWER JAW TO FORK OF TAIL)

FORWARD TO NMFS ADDRESS ON TAG, TO AFRF
4904 N. HARBOR DRIVE, SAN DIEGO, CALIF., OR
STATE FISHERIES AGENCIES.

Figure 2.—Inside cover of logbook containing information concerning recovery of tagged albacore.

the logbook records are mailed by fishermen to one of the State fisheries agencies or NMFS.

About 900 of the new logbooks were distributed to fishermen for use during the 1973 and 1974 albacore fishing seasons. In 1973, logbooks or interviews were received from 470 boats for a total of 813 trips representing 7,260 boat-days of fishing. The latter represents about 26 percent of the 27,416 total number of boat-days of fishing for the 1973 fishing season as estimated by California Department of Fish and Game (Hooker, pers. commun.). In 1974, logbooks or interviews were received from 520 boats for a total of 999 trips representing 10,333 boat-days of fishing. An estimate of the total number of boat-days for the 1974 fishing season is not available at this time.

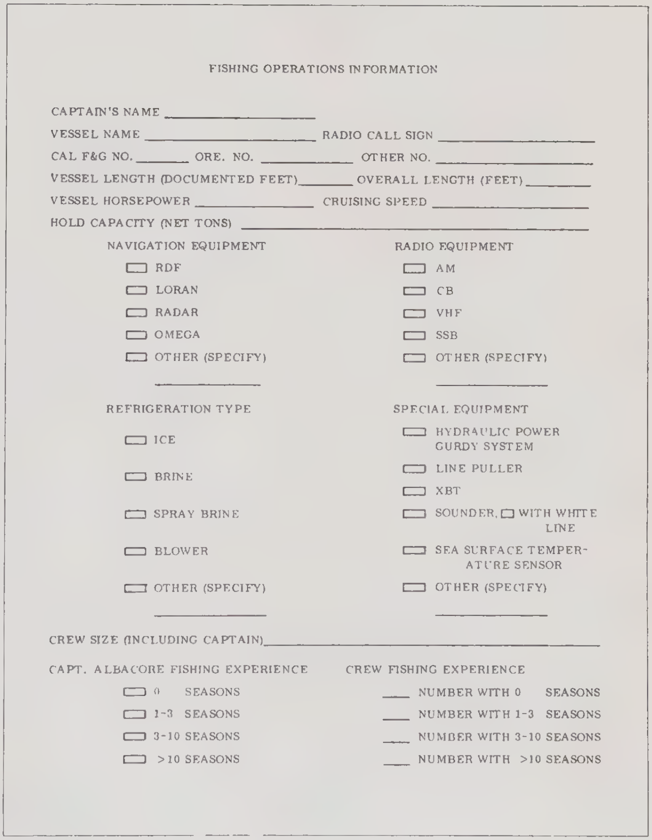
It can be seen in Table 1 that a) the number of boats which kept logbooks or were interviewed, b) the number of boat-days in a season for which catch and effort data were recorded, and c) the mean number of days that boats kept logbooks (or interview data are available) are higher in 1973 and 1974 than they were on the average during the 1961-1970 period.

We expect that the increase in logbook and interview coverage which was observed between 1973, when the

Table 1.—Number of boats that kept logbooks or were interviewed, number of boat-days for which catch and effort data were recorded, and mean number of days boats kept logbooks or interview data are available.

Year	Number of boats	Number of boat-days	Mean number of days log kept
1961-70	[1]418	[1] 6,025	[1]14.4
1973	470	7,260	15.5
1974	520	10,333	19.9

[1]Mean value for 1961-1970.



FISHING OPERATIONS INFORMATION

CAPTAIN'S NAME __________
VESSEL NAME __________ RADIO CALL SIGN __________
CAL F&G NO. _____ ORE. NO. _____ OTHER NO. _____
VESSEL LENGTH (DOCUMENTED FEET) _____ OVERALL LENGTH (FEET) _____
VESSEL HORSEPOWER __________ CRUISING SPEED __________
HOLD CAPACITY (NET TONS) __________

NAVIGATION EQUIPMENT

- ☐ RDF
- ☐ LORAN
- ☐ RADAR
- ☐ OMEGA
- ☐ OTHER (SPECIFY) __________

RADIO EQUIPMENT

- ☐ AM
- ☐ CB
- ☐ VHF
- ☐ SSB
- ☐ OTHER (SPECIFY) __________

REFRIGERATION TYPE

- ☐ ICE
- ☐ BRINE
- ☐ SPRAY BRINE
- ☐ BLOWER
- ☐ OTHER (SPECIFY) __________

SPECIAL EQUIPMENT

- ☐ HYDRAULIC POWER GURDY SYSTEM
- ☐ LINE PULLER
- ☐ XBT
- ☐ SOUNDER, ☐ WITH WHITE LINE
- ☐ SEA SURFACE TEMPERATURE SENSOR
- ☐ OTHER (SPECIFY) __________

CREW SIZE (INCLUDING CAPTAIN) __________

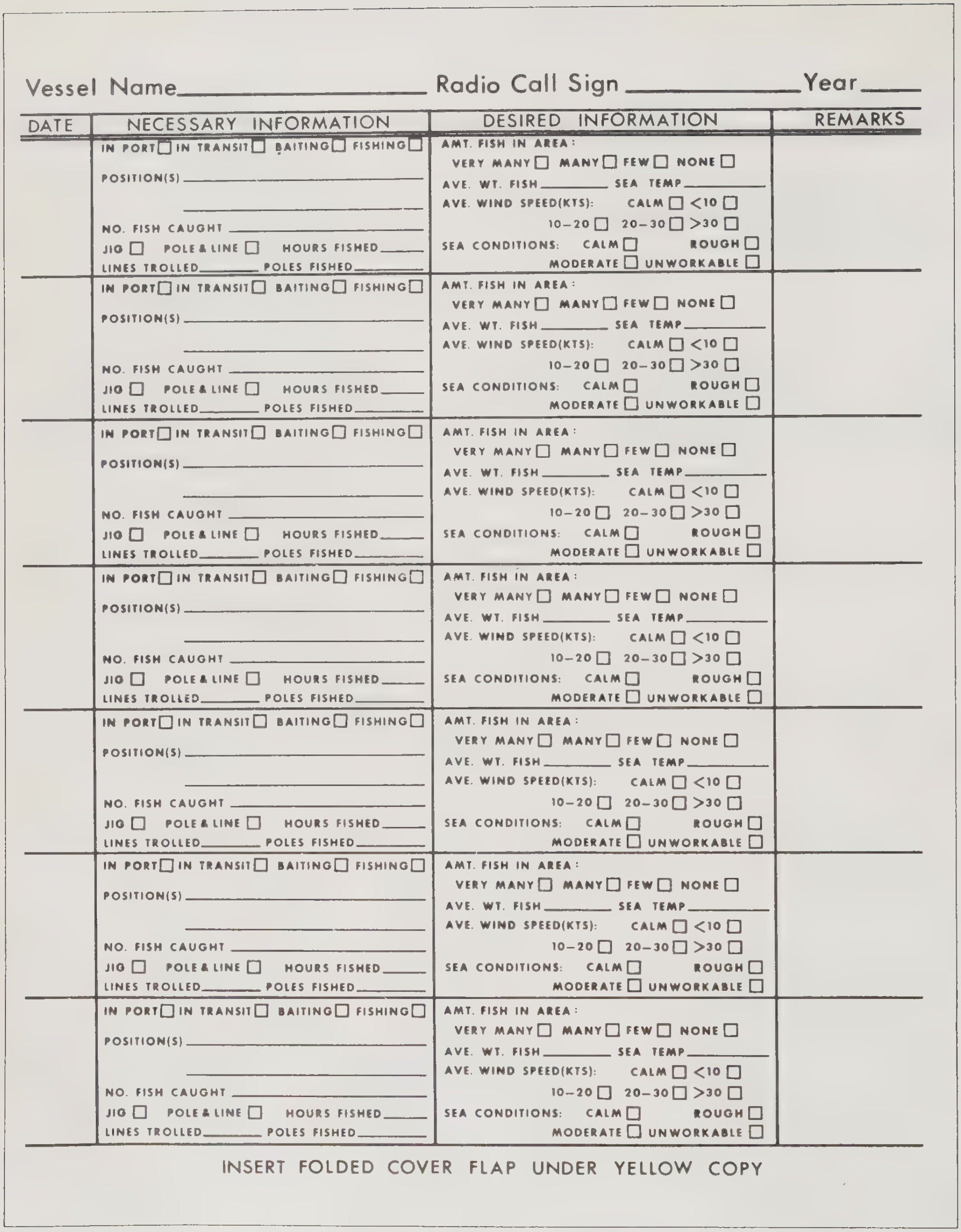
CAPT. ALBACORE FISHING EXPERIENCE

- ☐ 0 SEASONS
- ☐ 1-3 SEASONS
- ☐ 3-10 SEASONS
- ☐ >10 SEASONS

CREW FISHING EXPERIENCE

- ____ NUMBER WITH 0 SEASONS
- ____ NUMBER WITH 1-3 SEASONS
- ____ NUMBER WITH 3-10 SEASONS
- ____ NUMBER WITH >10 SEASONS

Figure 3.—Fishing operations information sheet from U.S. West Coast Albacore Logbook.



Vessel Name________________ Radio Call Sign ____________ Year_____

DATE	NECESSARY INFORMATION	DESIRED INFORMATION	REMARKS
	IN PORT ☐ IN TRANSIT ☐ BAITING ☐ FISHING ☐ POSITION(S) ________ ________ NO. FISH CAUGHT ________ JIG ☐ POLE & LINE ☐ HOURS FISHED ____ LINES TROLLED ____ POLES FISHED ____	AMT. FISH IN AREA: VERY MANY ☐ MANY ☐ FEW ☐ NONE ☐ AVE. WT. FISH ____ SEA TEMP ____ AVE. WIND SPEED(KTS): CALM ☐ <10 ☐ 10–20 ☐ 20–30 ☐ >30 ☐ SEA CONDITIONS: CALM ☐ ROUGH ☐ MODERATE ☐ UNWORKABLE ☐	
	IN PORT ☐ IN TRANSIT ☐ BAITING ☐ FISHING ☐ POSITION(S) ________ ________ NO. FISH CAUGHT ________ JIG ☐ POLE & LINE ☐ HOURS FISHED ____ LINES TROLLED ____ POLES FISHED ____	AMT. FISH IN AREA: VERY MANY ☐ MANY ☐ FEW ☐ NONE ☐ AVE. WT. FISH ____ SEA TEMP ____ AVE. WIND SPEED(KTS): CALM ☐ <10 ☐ 10–20 ☐ 20–30 ☐ >30 ☐ SEA CONDITIONS: CALM ☐ ROUGH ☐ MODERATE ☐ UNWORKABLE ☐	
	IN PORT ☐ IN TRANSIT ☐ BAITING ☐ FISHING ☐ POSITION(S) ________ ________ NO. FISH CAUGHT ________ JIG ☐ POLE & LINE ☐ HOURS FISHED ____ LINES TROLLED ____ POLES FISHED ____	AMT. FISH IN AREA: VERY MANY ☐ MANY ☐ FEW ☐ NONE ☐ AVE. WT. FISH ____ SEA TEMP ____ AVE. WIND SPEED(KTS): CALM ☐ <10 ☐ 10–20 ☐ 20–30 ☐ >30 ☐ SEA CONDITIONS: CALM ☐ ROUGH ☐ MODERATE ☐ UNWORKABLE ☐	
	IN PORT ☐ IN TRANSIT ☐ BAITING ☐ FISHING ☐ POSITION(S) ________ ________ NO. FISH CAUGHT ________ JIG ☐ POLE & LINE ☐ HOURS FISHED ____ LINES TROLLED ____ POLES FISHED ____	AMT. FISH IN AREA: VERY MANY ☐ MANY ☐ FEW ☐ NONE ☐ AVE. WT. FISH ____ SEA TEMP ____ AVE. WIND SPEED(KTS): CALM ☐ <10 ☐ 10–20 ☐ 20–30 ☐ >30 ☐ SEA CONDITIONS: CALM ☐ ROUGH ☐ MODERATE ☐ UNWORKABLE ☐	
	IN PORT ☐ IN TRANSIT ☐ BAITING ☐ FISHING ☐ POSITION(S) ________ ________ NO. FISH CAUGHT ________ JIG ☐ POLE & LINE ☐ HOURS FISHED ____ LINES TROLLED ____ POLES FISHED ____	AMT. FISH IN AREA: VERY MANY ☐ MANY ☐ FEW ☐ NONE ☐ AVE. WT. FISH ____ SEA TEMP ____ AVE. WIND SPEED(KTS): CALM ☐ <10 ☐ 10–20 ☐ 20–30 ☐ >30 ☐ SEA CONDITIONS: CALM ☐ ROUGH ☐ MODERATE ☐ UNWORKABLE ☐	
	IN PORT ☐ IN TRANSIT ☐ BAITING ☐ FISHING ☐ POSITION(S) ________ ________ NO. FISH CAUGHT ________ JIG ☐ POLE & LINE ☐ HOURS FISHED ____ LINES TROLLED ____ POLES FISHED ____	AMT. FISH IN AREA: VERY MANY ☐ MANY ☐ FEW ☐ NONE ☐ AVE. WT. FISH ____ SEA TEMP ____ AVE. WIND SPEED(KTS): CALM ☐ <10 ☐ 10–20 ☐ 20–30 ☐ >30 ☐ SEA CONDITIONS: CALM ☐ ROUGH ☐ MODERATE ☐ UNWORKABLE ☐	
	IN PORT ☐ IN TRANSIT ☐ BAITING ☐ FISHING ☐ POSITION(S) ________ ________ NO. FISH CAUGHT ________ JIG ☐ POLE & LINE ☐ HOURS FISHED ____ LINES TROLLED ____ POLES FISHED ____	AMT. FISH IN AREA: VERY MANY ☐ MANY ☐ FEW ☐ NONE ☐ AVE. WT. FISH ____ SEA TEMP ____ AVE. WIND SPEED(KTS): CALM ☐ <10 ☐ 10–20 ☐ 20–30 ☐ >30 ☐ SEA CONDITIONS: CALM ☐ ROUGH ☐ MODERATE ☐ UNWORKABLE ☐	

INSERT FOLDED COVER FLAP UNDER YELLOW COPY

Figure 4.—Fishing log sheet from U.S. West Coast Albacore Logbook.

new logbook was introduced and port sampling was expanded, and 1974 will continue. In general it appears that fisherman acceptance of the logbook and interview system has increased and we anticipate that the acceptance will increase more as fishermen become more familiar with the data collection system and are provided feedback from it.

COASTWIDE DATA SYSTEM

A coastwide albacore data system has been developed to provide a mechanism whereby the albacore catch and effort data collected by the individual States may be combined and uniformly standardized to obtain information over the entire range of the U.S. albacore fishery in a timely manner. This information is then readily available for resource assessment, fishery-oceanography, and other studies involving that segment which is harvested by the U.S. fishery, or the entire north Pacific albacore population if the U.S. data are combined with similar data from other nations fishing on the north Pacific population of albacore. Concerning the latter, for example, a study was recently initiated between the NMFS and the Japanese Far Seas Fisheries agency to cooperatively study the population dynamics of the north Pacific albacore.

The processing, standardization, and management of the U.S. logbook data are shared by the states and NMFS. Processing, including editing and quality control, is accomplished by state fishery personnel who examine each logbook for completeness and errors. (California and Oregon have capabilities for complete processing of the albacore fishery data collected by their respective fishery agencies, while at present, some processing of data collected by the State of Washington fishery agency is shared by California and NMFS.) Boat lengths, radio call signs, and vessel registration or license numbers are checked through State registration records. Catch locations, which are usually recorded as Loran coordinates, are also assigned to a 1° latitude-longitude quadrangle. In addition, code numbers are assigned to the records for each vessel for later use to protect the confidentiality of the information provided. The data are keypunched and transferred to magnetic computer tape, and further quality control is exercised. The assignment of the data to the proper 1° quadrangle is checked and the average weight for fish landed is compared against arbitrary limits to eliminate unrealistic weight data. The landing date on the log is also checked against the landing date on the state records of the buyer's receipts. The states use the finalized data tapes to prepare various summaries for their needs.

In addition, a computer tape containing the edited information from the logbooks with boat names replaced by code numbers is prepared for transfer to NMFS. These scientists check by computer for duplication of records and a final basic data tape is prepared. The fishing effort then is standardized using a modified version of the computer program FPOW (Berude and Abramson, 1972) as described by Laurs, Clemens, and Hreha[3]. The fishing effort standardization involves a three-way process to adjust for differences in fishing power among 1) vessel length, 2) time during the fishing season, and 3) geographic area of fishing. Fishing effort for jig vessels of all length classes is expressed in terms of a 45-foot jigboat and estimates of mean standardized catch per unit effort are computed by 15-day period and 1° quadrangle. Paucity of information has limited attempts to generate catch per unit data for baitboats, and efforts are being made to increase the logbook coverage of baitboats which catch about 25 percent of the albacore taken in the U.S. albacore fishery.

The standardized catch per unit of effort data for the U.S. albacore fishery are put on computer tape by NMFS where they are archived and are being used in albacore research studies. In addition, copies of the data tape(s) for the entire fishery or for a specified portion are available to the state fishery agencies. Also should the north Pacific albacore tuna population come under some form of management, the data could be readily available to resource managers in a relatively timely manner.

The processing, merging, and standardization of the albacore catch and effort data are usually completed in April or early May following the albacore fishing season, which usually lasts from July to early November.

DISSEMINATION OF CATCH-EFFORT INFORMATION TO COOPERATING FISHERMEN

In discussions with albacore fishing industry representatives concerning the need to obtain increased catch and effort information and the design of the proposed new logbook, they emphasized the desire of having timely feedback to fishermen of catch information summarized from the logbooks. The rationale for doing so was that fishermen would be more likely to keep a logbook if they could see tangible results and possibly benefit from them.

As an incentive for fishermen to keep logbooks, charts showing catch per unit of effort summarized by 15-day period and 1° quadrangle (Fig. 5) and size composition by area (Fig. 6) for the preceding season are distributed to fishermen with logbooks for use during the upcoming season. The charts are also distributed to other members of the albacore fishing industry who request them, e.g., buying station operators, processors, boat dock operators, etc. The charts are issued as a cooperative product of the state fishery agencies and NMFS.

Comments received from fishermen indicate satisfaction with the catch and size composition charts. According to some fishermen, they are more consistent and conscientious in keeping logbooks because of the receipt of the catch charts.

While the dissemination of the catch charts to fishermen appears to be popular and successful, questions

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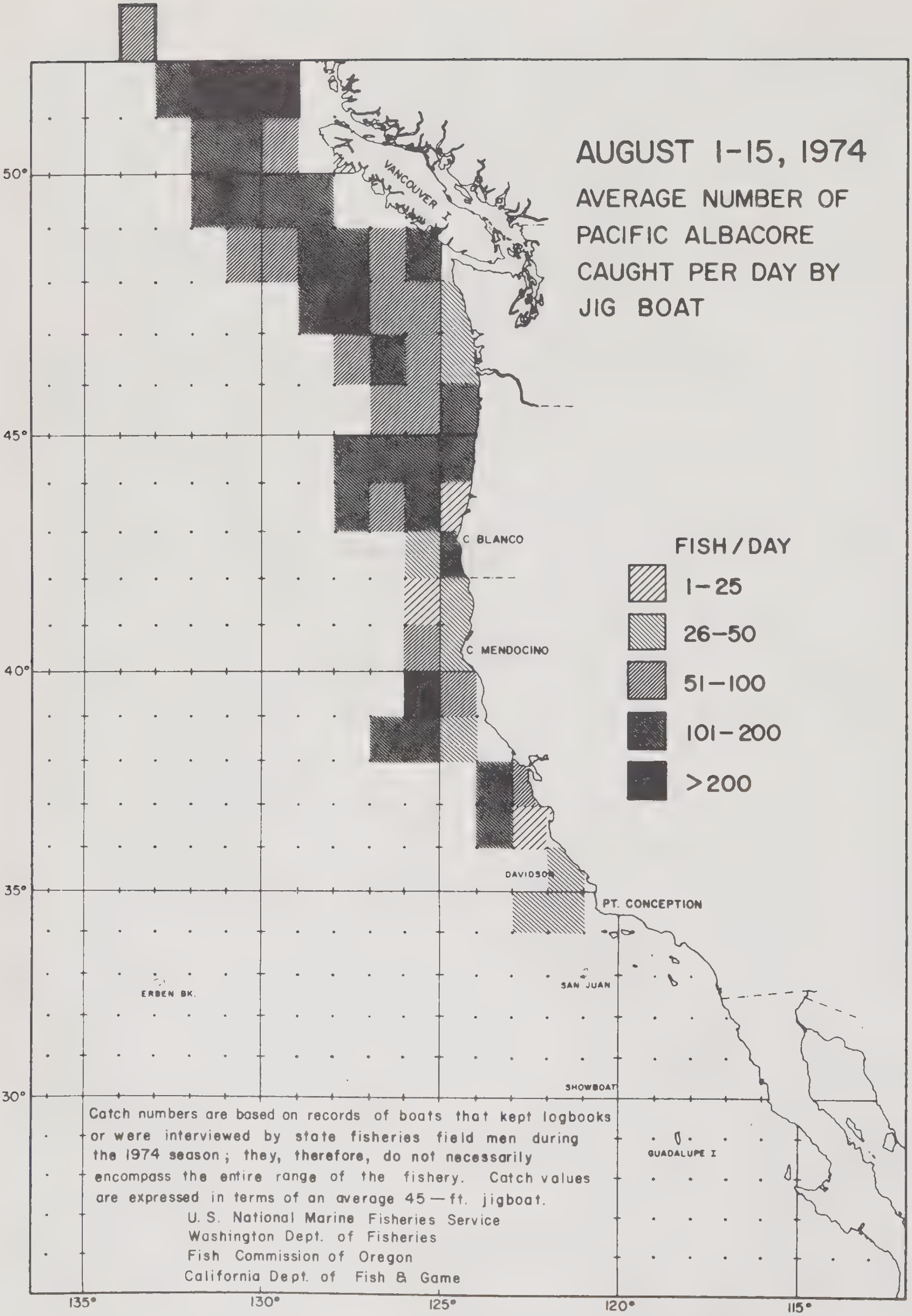
[3] Laurs, R. M., H. B. Clemens, and L. H. Hreha. Catch per unit effort of albacore tuna, *Thunnus alalunga* (Bonnaterre) caught by U.S. jig vessels during 1961-1970. In preparation.


AUGUST 1-15, 1974
AVERAGE NUMBER OF PACIFIC ALBACORE CAUGHT PER DAY BY JIG BOAT

FISH/DAY
▨ 1–25
▨ 26–50
▨ 51–100
▨ 101–200
■ >200
VANCOUVER I.
C. BLANCO
C. MENDOCINO
DAVIDSON
PT. CONCEPTION
ERBEN BK.
SAN JUAN
SHOWBOAT
GUADALUPE I.
50°
45°
40°
35°
30°
135°
130°
125°
120°
115°

Catch numbers are based on records of boats that kept logbooks or were interviewed by state fisheries field men during the 1974 season; they, therefore, do not necessarily encompass the entire range of the fishery. Catch values are expressed in terms of an average 45 — ft. jigboat.

U. S. National Marine Fisheries Service
Washington Dept. of Fisheries
Fish Commission of Oregon
California Dept. of Fish & Game

Figure 5.—Mean catch per unit effort of albacore tuna by 15-day period and 1° quadrangle.

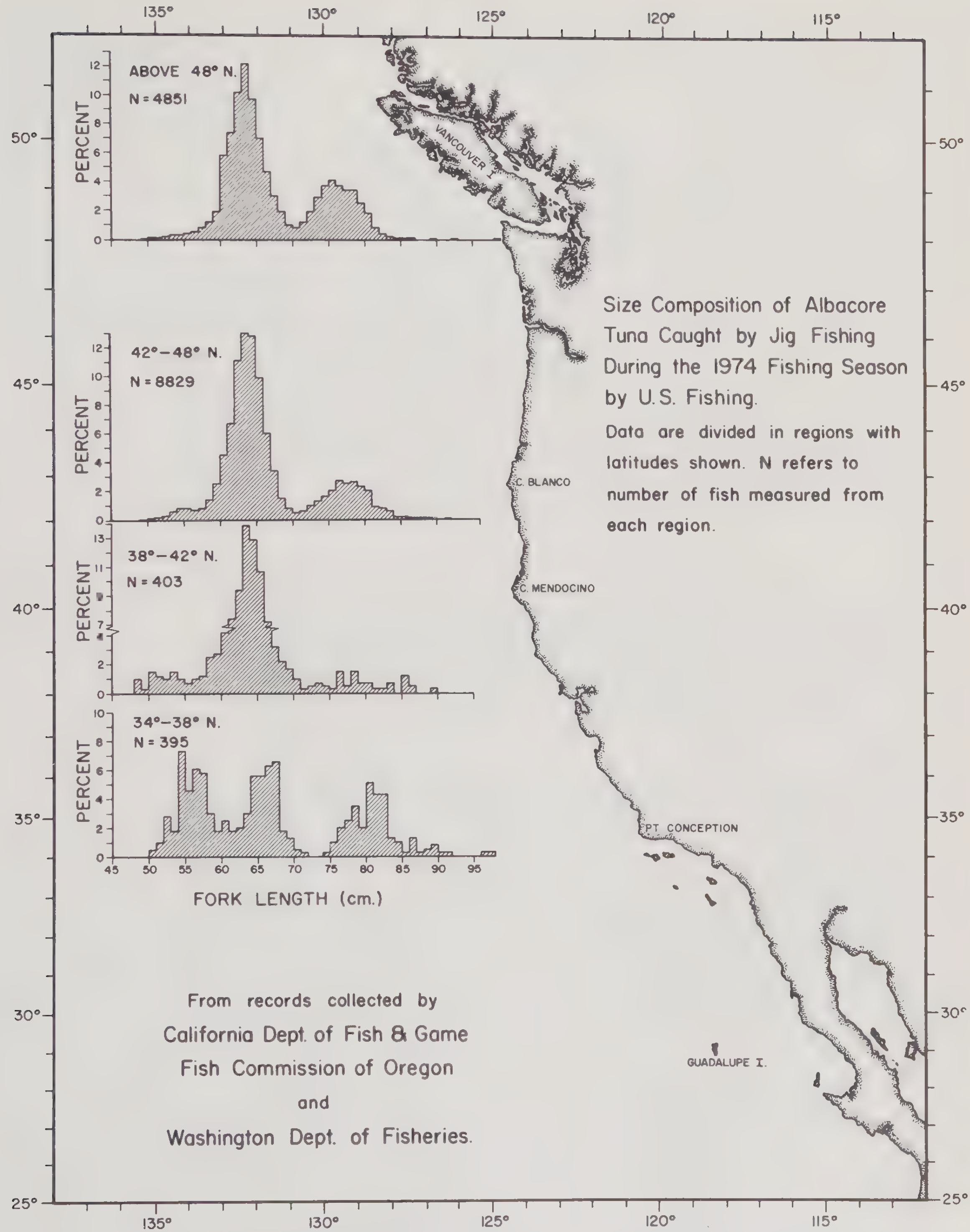


Figure 6.—Size composition of commercially caught albacore tuna by geographic area.

by fishermen to port samplers indicate that an educational program concerning the importance and scientific use of catch per unit of effort would be very beneficial. A limited educational program has been provided to fishermen by NMFS and state fishery scientists at fishermen's association meetings and Sea Grant sponsored "Town Hall" meetings or workshops. However, we feel that additional educational efforts would result in an increase in the number of fishermen who keep logbooks, the number of boat-days that a given fisherman would keep a logbook, and improve the overall quality of the logbook data.

ACKNOWLEDGMENTS

We wish to express our appreciation to Robert F. Insinger and Jack Bowland, former and present managers of the Western Fishboat Association respectively, and Frank Martin, President of the American Fishermen's Association, for their constructive comments and assistance in the development of the uniform albacore logbook; to John Harville, Executive Secretary of the Pacific Marine Fisheries Commission for his support; and to the many albacore fishermen who have kept logbooks and made comments concerning their use. A major portion of the costs for printing the logbook and the expanded port sampling program was funded by Sea Grant Contract 04-3-158-35, administered by the Pacific Marine Fisheries Commission.

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MFR Paper 1166. From Marine Fisheries Review, *Vol. 37, No. 11, November 1975. Copies of this paper, in limited numbers, are available from D825, Technical Information Division, Environmental Science Information Center, NOAA, Washington, DC 20235. Copies of* Marine Fisheries Review *are available from the Superintendent of Documents, U.S. Government Printing Office, Washington, DC 20402 for $1.10 each.*

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THE ASSOCIATION OF OCEANIC BOUNDARY FEATURES AND ALBACORE TUNA IN THE NORTHEAST PACIFIC

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ABSTRACT

The distribution and apparent abundance of albacore tuna during the early season migration toward the U.S. west coast fishery are related to the oceanographic conditions of the Transition Zone and associated oceanic frontal structure. Cooperative surveys involving a National Marine Fisheries Service (NMFS) research vessel and chartered fishing vessels were conducted during 1972, 1973, and 1974, in a region centered 500 to 1,000 nautical miles offshore California. The findings show that albacore are more readily available within the Transition Zone than outside it and that year-to-year variations in ocean structure are reflected in variations in albacore distribution.

INTRODUCTION

The North Pacific albacore tuna *Thunnus alalunga* (Bonneterre) is a wide ranging species which spawns in the central subtropical Pacific, performs transpacific migrations, and supports important commercial fisheries in the western, central western, and eastern North Pacific. Marked variations in the distribution and apparent abundance of albacore occur in the northeast Pacific as indicated by major shifts in the location of the U.S. fishery off the Pacific west coast.

In order to evaluate factors which may affect variations in the distribution and apparent abundance of albacore in the northeast Pacific, early season surveys were conducted in 1972, 1973, and 1974, to investigate the shoreward migration of albacore tuna into the U.S. west coast fishery and the associated marine environmental factors that could influence the migration, and to examine the early season distribution and apparent abundance of albacore in the offshore area. The surveys were designed to improve our understanding of the underlying factors affecting the prediction of the onset and subsequent development of the fishery, and to examine the possibilities for fishermen to extend the albacore fishery farther offshore and to start the fishery earlier than the season usually begins. Specifically, the surveys were conducted to examine the migration patterns of albacore tuna into North American waters and the relationship of the patterns to the eastern terminus of the Transition Zone between Pacific subarctic and Pacific central waters and to evaluate the fishery potential in offshore waters.

The surveys were carried on cooperatively by the National Marine Fisheries Service (NMFS) and the albacore fishing industry through the American Fishermen's Research Foundation (AFRF).

METHODS

The general work plan employed during each of the offshore surveys involved one NMFS research vessel (*Townsend Cromwell* in 1972 and *David Starr Jordan* in 1973 and 1974) and a group of 5 to 12 commercial albacore fishing vessels on charter to AFRF, working cooperatively to evaluate the distribution and apparent abundance of albacore in the offshore area, and to conduct concurrent oceanographic observations. The research vessel collected physical, chemical, and biological oceanographic data and conducted supplementary fishing activities, and the fishing vessels conducted exploratory fishing, fish tagging, and collected surface and subsurface temperature data. The oceanographic findings made on meridional transects were used in directing the exploratory fishing operations, particularly at the onset of each survey. And, in several instances, especially in 1973 and 1974, the findings of large bodies of fish were used to redirect the research vessel to conduct detailed oceanographic observations in the nearby vicinity.

Operations Aboard Research Vessels

Three meridional oceanographic sections were taken along 135°, 137°30', and 140° W between 31° to 41° N in 1972 and 1973; in 1974 the middle section, portions of the section along 135° W, and additional ones were taken (Figure 1). Hydrographic stations were occupied at 25 to 30 nautical-mile intervals; Figure 2 shows station positions occupied in 1973 and is typical of the station plans occupied in 1972 and 1974. Observations included 1) salinity-temperature-depth profiles to 500 or 1,000 m using a STD;[1] 2) Nansen bottle or General Oceanics rosette sampler bottle cast for collection of water samples for determination of dissolved oxygen, chlorophyll, nutrients, and salinity for STD calibration; 3) oblique zooplankton hauls to 200 m using CalCOFI 1-m plankton nets and simultaneous surface hauls with neuston plankton nets; and 4) at night stations oblique midwater trawl hauls to 200 m using an Isaacs-Kidd midwater trawl. Also, surface temperature, salinity, and chlorophyll were recorded continuously while underway. The discrete subsurface and continuous surface chlorophyll measurements were made using fluorometric methods.

Generally, 10 lines (five on Cromwell cruise in 1972) were trolled for albacore on transits between oceanographic stations during daylight hours. In some regions that were not covered by fishing vessels, trolling was carried on by the research vessel throughout daylight hours. On such fishing days, three or four expendable bathythermograph (XBT) drops were made in addition to the continuous monitoring of surface temperature, salinity, and chlorophyll.

Operations Aboard Fishing Vessels

The AFRF charter vessels which took part in the offshore surveys were all jigboats, except for two baitboats in 1973, which were outfitted to conduct either live bait fishing or jig fishing. Twelve fishing vessels participated in the operations in 1972 and 1973 and five in 1974.

The fishing vessels sailed in groups of four from San Diego, California and Astoria, Oregon at 15 to 20 day intervals during 1972 and 1973, and all vessels sailed together from San Diego in 1974. The vessels usually worked in pairs for safety reasons. A schematic diagram of the cruise tracks for the 1972, 1973, and 1974 offshore surveys is shown in Figure 3.

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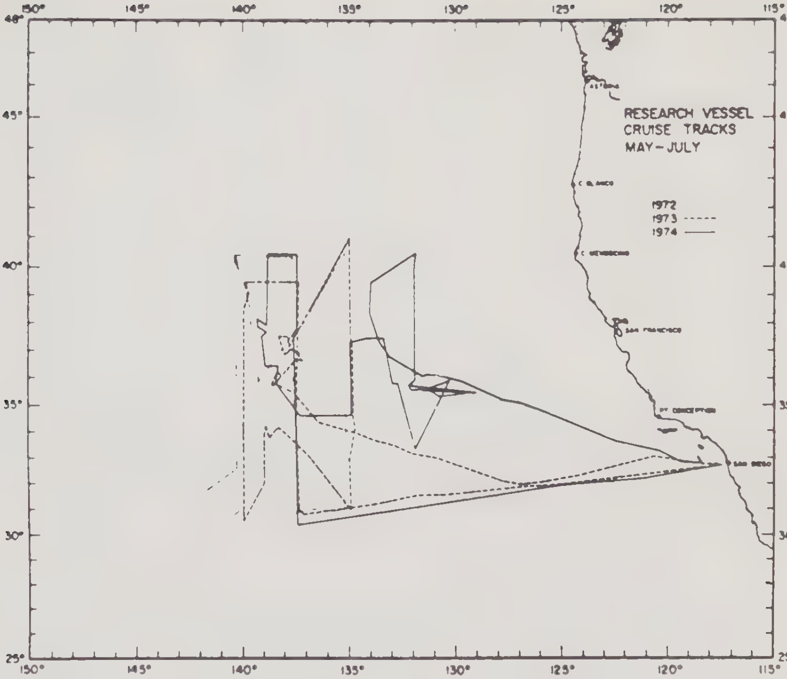
[1] Plessey model 9006 electronic salinity-temperature-depth profiler.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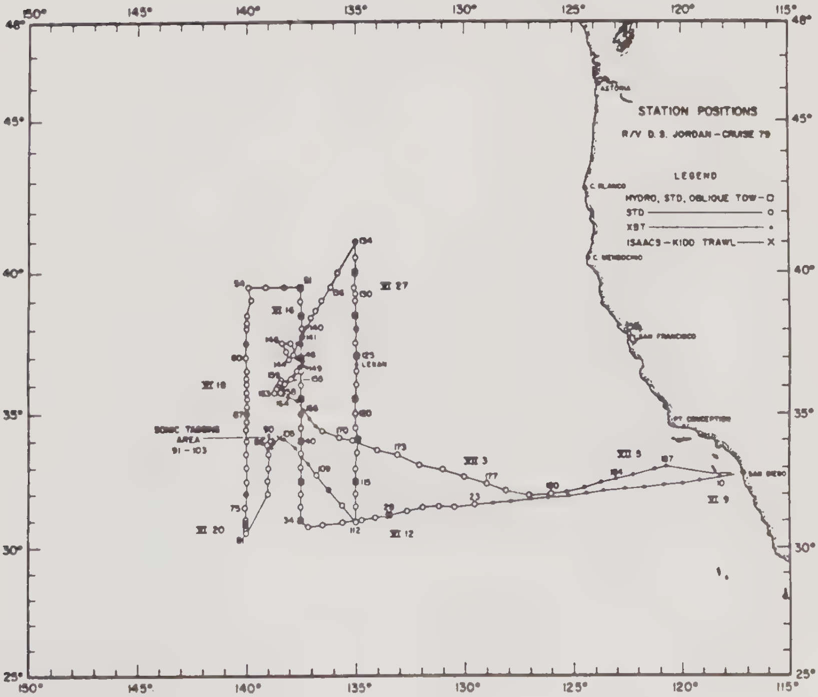
C. MENDOCINO
SAN FRANCISCO
PT CONCEPTION
SAN DIEGO
RESEARCH VESSEL
CRUISE TRACKS
MAY - JULY
1972
1973 -----
1974 ——

Figure 1. Research vessel cruise tracks for the 1972, 1973, and 1974 offshore research surveys.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SAN FRANCISCO
PT CONCEPTION
SAN DIEGO
STATION POSITIONS
R/V D. S. JORDAN - CRUISE 79
LEGEND
HYDRO, STD, OBLIQUE TOW - □
STD ○
XBT •
ISAACS - KIDD TRAWL X
SONIC TAGGING
AREA
91 - 103
VI 27
VI 16
VI 18
VI 20
VI 12
VII 3
VII 5
VI 9
134
130
125
120
115
112
109
34
29
23
75
80
87
90
170
173
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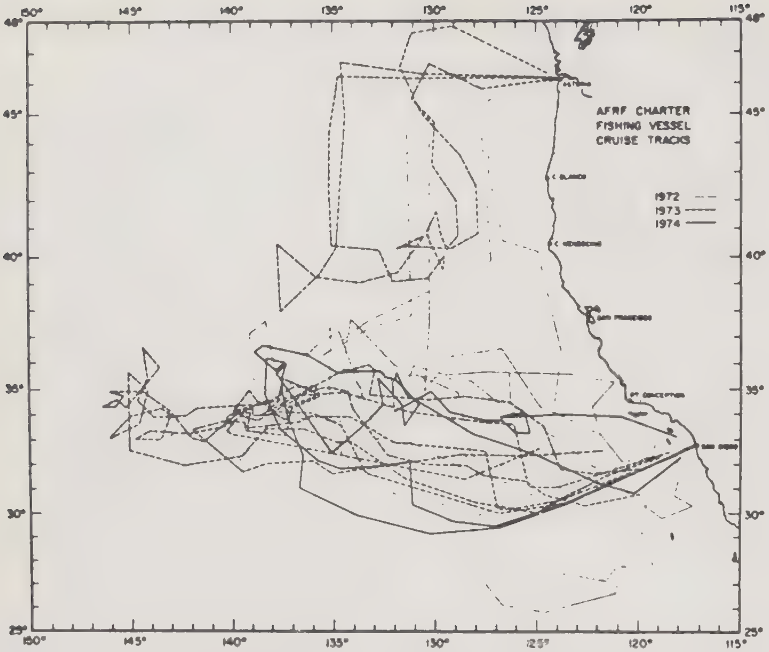
187
10

Figure 2. Track and station positions for R/V David Starr Jordan cruise 79, June 9 through July 6, 1973.


AFRF CHARTER
FISHING VESSEL
CRUISE TRACKS
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SAN DIEGO

Figure 3. AFRF charter fishing vessel cruise tracks for the 1972, 1973, and 1974 offshore research surveys.

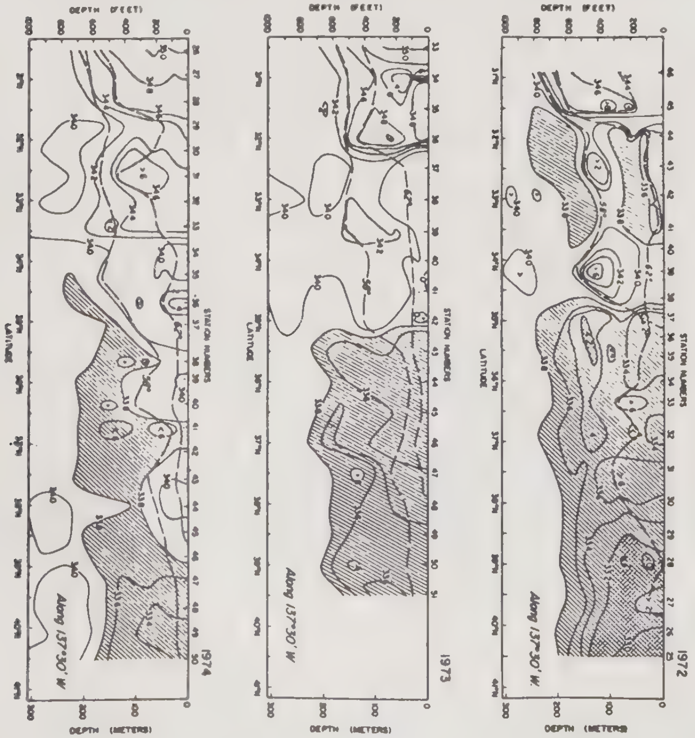


Figure 4. Vertical sections of salinity along 137° 30' W for 1972 (upper), 1973 (middle), and 1974 (lower). Salinity below 33.8% is shown hatched and salinity above 34.2% is shaded by a dot pattern. The 58° F (14.4° C) and 62° F (16.7° C) isotherms are shown by heavy dashed lines.

The fishing operations were conducted using standard commercial albacore fishing equipment employing regular commercial fishing methods. Daily records pertaining to fishing operations were maintained aboard each vessel, including the number of fish caught, the fork length of most fish caught, positions where fishing was started and ended, the amount of fishing effort expended, and fishing conditions and fish signs. In addition, sea surface temperatures, water color, sea conditions, and surface weather conditions were recorded.

Half of the fishing vessels chartered in 1972 and 1973, and all in 1974 were equipped with an XBT; generally one or two XBTs were launched each day. Sea surface temperature measurements were made using bucket thermometers.

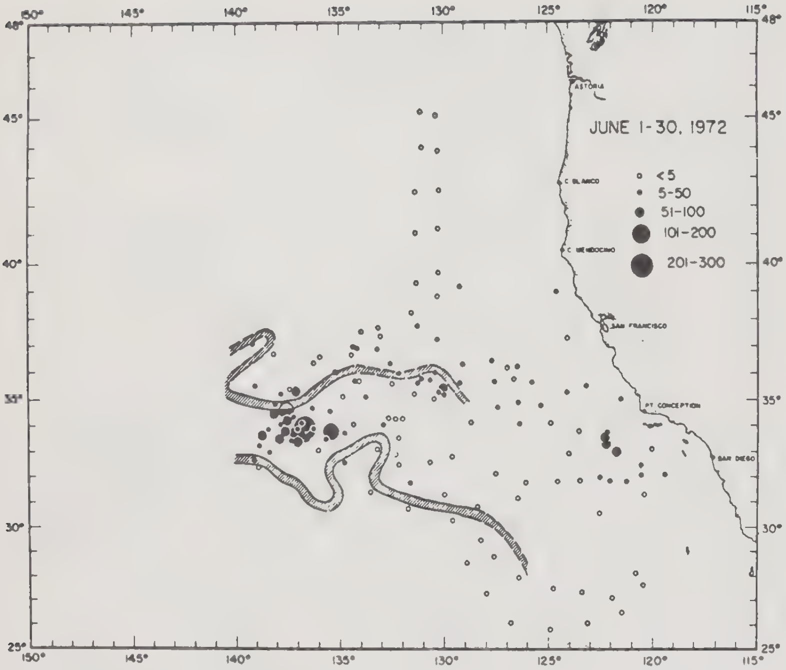
THE DISTRIBUTION AND APPARENT ABUNDANCE OF ALBACORE IN OFFSHORE WATERS DURING SURVEY PERIODS

Over 28,000 albacore were caught by the charter and research vessels during the three offshore surveys. In 1972 and 1973 the apparent abundance of albacore was highest between 32° and 35° N and 135° and 140° W, and 32° and 35° N and 135° and 145° W, respectively. In both of these years the largest catches were made offshore of 135° W with small or no catches made in the region between the offshore area and inshore waters within 150 miles of the coast where fishing takes place during the traditional albacore fishing season. This pattern of the distribution of albacore catches appeared to be related to oceanographic frontal structure present at the time the surveys were conducted and is discussed in more detail later. In 1974, the pattern of albacore apparent abundance was similar in some respects to that observed in 1972 and 1973, and different in others. High catches were again made in the area offshore of 135° W, but over a larger latitudinal range, 31° to 36° N, and somewhat more scattered than in the two preceding years. Also, high catches were made at about 32° to 35° N, 125° W in the region between the offshore area of high catches and inshore waters where fishing normally takes place. As is discussed later, oceanographic conditions were different in 1974 than in 1973 and 1972, and the distribution of albacore catches appeared to be related to the oceanographic frontal structure prevailing at the time of the 1974 survey.

THE MARINE ENVIRONMENT

The distribution and apparent abundance of albacore in the offshore region during all three surveys were related to the oceanographic conditions of the Transition Zone waters and the development of associated oceanic frontal structure. The Transition Zone is a region of mixing between cold, low salinity subarctic waters to the north and warm, saline subtropic waters to the south. The Transition Zone waters are found in a zonal band across the North Pacific middle latitudes within the westward-flowing North Pacific Current. They are bounded by abrupt horizontal gradients in temperature and salinity. The bounding gradient region to the north is called the subarctic front and that to the south is called the subtropic front. The dynamic processes which produce and maintain the gradients also enrich these waters, which give reason why these regions are biologically important to albacore. To the east of 135° W, the North Pacific Current turns southeast and south as does the Transition Zone, and the boundary gradients begin to lose their continuity.

Temperature and salinity data are used to identify the Transition Zone as distinct from the water masses to the north and south. Three oceanographic sections of the vertical distribution of temperature and salinity along 137° 30' W taken in 1972, 1973, and 1974 are given in Figure 4. In 1972 and 1973, the


JUNE 1-30, 1972
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SAN FRANCISCO
PT CONCEPTION
SAN DIEGO
150° 145° 140° 135° 130° 125° 120° 115°
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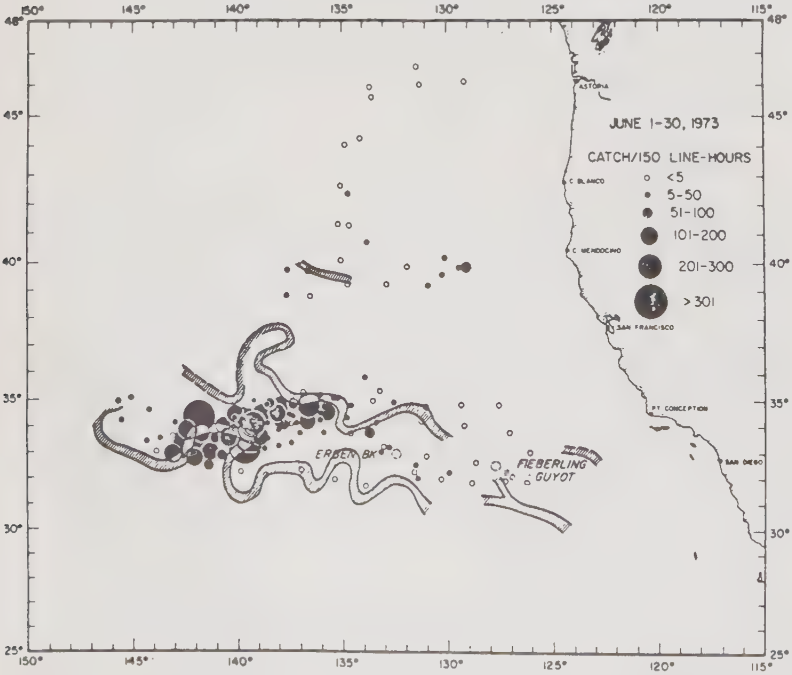
Figure 5. The standardized catch (per 150 line-hours) of albacore taken in June 1972 by the NMFS-AFRF survey plotted over a graphical depiction of the oceanic fronts that bound the Transition Zone.


JUNE 1-30, 1973
CATCH/150 LINE-HOURS
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5-50
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101-200
201-300
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C. MENDOCINO
SAN FRANCISCO
PT CONCEPTION
SAN DIEGO
ERBEN BK
FIEBERLING GUYOT
150° 145° 140° 135° 130° 125° 120° 115°
48° 45° 40° 35° 30° 25°

Figure 6. The standardized catch (per 150 line-hours) of albacore taken in June 1972 by the NMFS-AFRF survey plotted over a graphical depiction of the oceanic fronts that bound the Transition Zone.

boundaries of the Transition Zone were well developed and readily identifiable. The subarctic waters (shown by hatching of salinity less than 33.8‰) lie to the north of 35° N and the subtropic waters (shown by dot-shading of salinity greater than 34.2 ‰) lie to the south of 31°30' N and 31° N, respectively. Between these water masses is the Transition Zone, the boundaries of which are made evident by the abrupt gradients in salinity extending from the surface to depths greater than 150 m. The temperature gradients are coincident with the salinity gradients. In Figure 4, the temperature field is simplified to two isotherms. The abrupt change in depth of the 62° F (16.7° C) isotherm is coincident with the subtropic boundary and that of the 58° F (14.4° C) isotherm is coincident with the subarctic boundary. The boundaries of the Transition Zone were poorly developed in 1974. In the section taken in 1974, the salinity gradients were more diffuse and the changes in depth of the isotherms more gradual and variable.

ALBACORE CATCHES IN RELATION TO OCEANIC FRONTS

Graphical depictions of the frontal gradients that form the boundaries of the Transition Zone[2] and standardized albacore catches[3] for June of each of the three surveys are shown in Figures 5, 6 and 7. These figures indicate that the catches were largely made within the Transition Zone in all 3 years.

During June 1972 and 1973, productive centers of fishing developed in the Transition Zone between 33° and 35° N and west of 135° W (Figures 5 and 6). These centers persisted for 2 and 3 weeks before fishing effort was withdrawn. In these years, the frontal structure was strongly developed and the Transition Zone easily identifiable. During June 1974 when the frontal structure was poorly developed and water masses boundary were less distinct, the catches were distributed over a larger range of latitude, 31° to 36° N (Figure 7). While the catches overall were substantial in 1974, they did not demonstrate the persistence in any area for more than a few days. Thus, the albacore continued to be oriented to Transition Zone waters but the influence of extensive lateral mixing between water masses and the diffuse nature of the boundary frontal structure apparently was not effective in concentrating the catches as had occurred in the previous 2 years.

The graphical depiction of frontal structure shown in Figure 7 outlines the location of the boundaries associated with Transition Zone water, however, they do not indicate the intensity of the gradients of the frontal structure. Whereas, in general, the frontal structure has been shown to have weak gradients during June 1974, one area did have abrupt gradients. The eastward protruding tongue of Transition Zone water centered at 35°30' N, 132°30' W had salinity gradients comparable to those found in previous years. Substantial catches persisted for a week in this one region.

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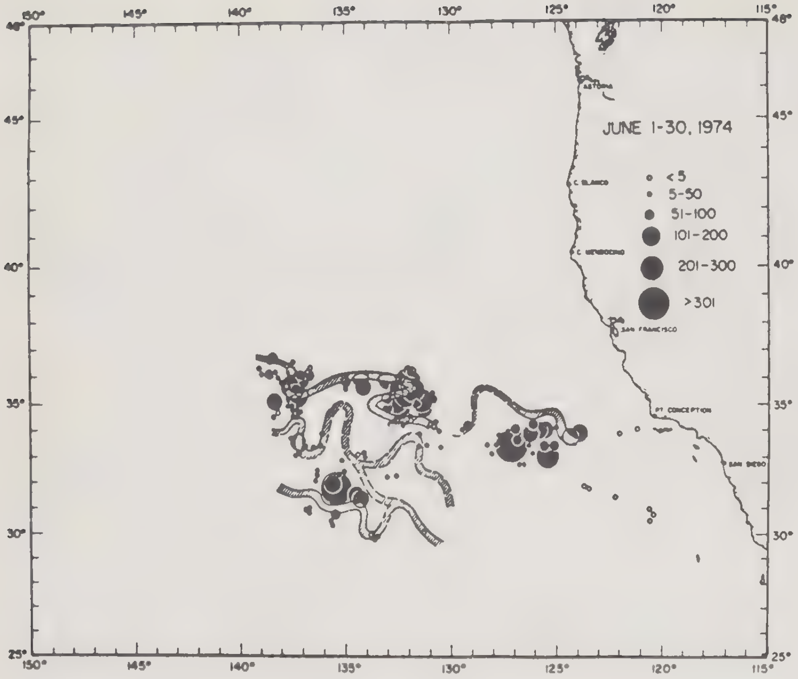
[2] The temperature and salinity fields measured by the research vessel augmented by the XBT data collected by the charter fishing vessels were analyzed to delineate the frontal gradients.

[3] Expressed as catch per 150 line-hours, which is equivalent to fishing 10 lines for 15 hours.



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ASTORIA
JUNE 1-30, 1974
C. BLANCO
C. MENDOCINO
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101-200
201-300
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SAN FRANCISCO
PT CONCEPTION
SAN DIEGO

Figure 7. The standardized catch (per 150 line-hours) of albacore taken in June 1974 by the NMFS-AFRF survey plotted over a graphical depiction of the oceanic fronts that bound the Transition Zone.

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Distribution, Relative Abundance, and Movement of Skipjack Tuna, *Katsuwonus pelamis*, in the Pacific Ocean Based on Japanese Tuna Longline Catches, 1964-67

WALTER M. MATSUMOTO[1]

ABSTRACT

Catch data of the Japanese tuna longline fishery from 1964 to 1967 were analyzed to determine the distribution, abundance, and movement of skipjack tuna, *Katsuwonus pelamis*, in offshore waters of the Pacific Ocean.

Large skipjack tuna, as well as larvae, were found to be concentrated mainly in the east central equatorial Pacific. Movement of skipjack tuna stocks was determined by following the shifting of high-CPUE (catch per unit effort) cells from one quarter to the next. The apparent movement of skipjack tuna stocks in the Pacific appeared to coincide with the circulation of the major ocean currents; counterclockwise in the southern hemisphere and clockwise in the northern hemisphere, except in the eastern Pacific where the current flow is counterclockwise. The movement patterns of high-CPUE suggested that skipjack tuna adults or their progeny could move from one area to the next. The movement pattern was used also to determine the probable migratory routes followed by skipjack tuna tagged in the eastern Pacific and recovered near the Hawaiian and Christmas islands.

INTRODUCTION

Skipjack tuna, *Katsuwonus pelamis*, are taken near the surface and at moderate depths in the Pacific Ocean, but the surface fisheries, utilizing pole and line and purse seine, account for about 99% of the catch. For various reasons, most of the catches throughout the major fisheries are made within 320 km (ca. 200 miles) of shore (Fig. 1). Consequently, although much has been learned about the skipjack tuna within the surface fisheries, knowledge of their distribution and movements in mid-oceanic areas is limited.

In an attempt to determine the population structure and migration of the skipjack tuna in mid-oceanic areas, Miyake (1968) examined the longline catch data of Japanese commercial (1956-64) and research (1949-65) vessels. He did not draw any conclusions from his study because he believed the data were inadequate.

Kasahara (1968) also examined the Japanese longline catch data to determine the distribution and centers of abundance of skipjack tuna in the Pacific Ocean. His report included hypothetical migratory routes of skipjack tuna as postulated by Naganuma (unpublished manuscript[2]) based on the catches and monthly variations in length frequencies of skipjack tuna taken by the Japanese longline fishery (year not given). Certain aspects about the routes postulated by Naganuma require clarification; for example, no return routes toward the equator are given for fish in the central and western North Pacific, and the direction of movement of skipjack tuna in the central South Pacific differs from the results of my study.

My study also is based upon the Japanese tuna longline catch data to determine centers of skipjack tuna abundance and, by tracing the seasonal shifting of high catch-rate areas, to derive the migration paths of skipjack tuna in the Pacific Ocean. As might be expected in studies of this kind, some degree of subjectivity was involved in the analyses. Nevertheless, models such as this are necessary first step in advancing our knowledge about the oceanwide movement of the skipjack tuna.

LONGLINE CATCH DATA

Source of Data

Several sources of tuna longline data are available, but the data are not all equally useful. Miyake (1968) gives a detailed account of the nature of these data. The best data are those published in the annual report of effort and catch statistics by area in the Japanese tuna longline fishery beginning with the year 1962 (Fisheries Agency of Japan, Research Division, 1965, 1966, 1967a, 1967b, 1968, 1969). However, because the Japanese Government's requirement that all fishing vessels submit copies of their fishing logbooks at the termination of each trip did not go into effect until 1963 and because the extent of longline fishing coverage in the eastern and southern Pacific was poor through the first quarter of 1963 (Miyake 1968), data for 1962 and 1963 are not included in this study.

Evaluation of Longline Data

The tuna longline is a passive gear designed to catch large fish about 70 to 145 m below the surface (Yoshihara 1954). Its design and fishing characteristics are not ideal for catching skipjack tuna, but in the absence of

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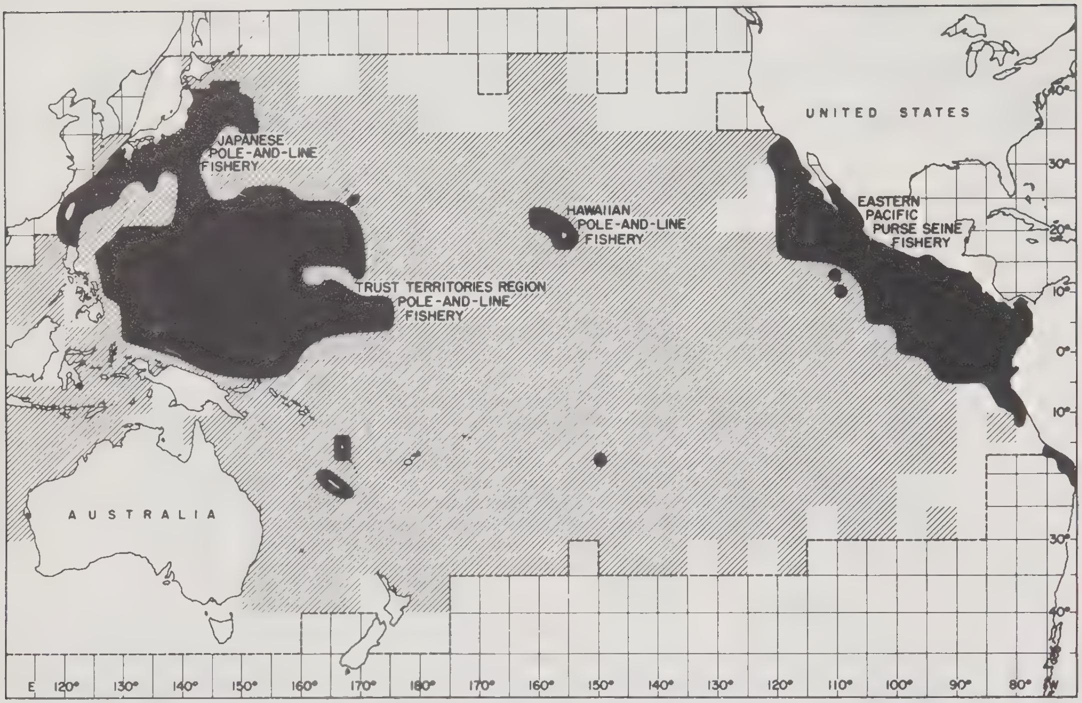
[2] Naganuma, A. (Unpubl. manuscr.) [Tohoku Regional Fisheries Research Laboratory, Shiogama City, Miyagi Prefecture, Japan.]


JAPANESE POLE-AND-LINE FISHERY
HAWAIIAN POLE-AND-LINE FISHERY
TRUST TERRITORIES REGION POLE-AND-LINE FISHERY
UNITED STATES
EASTERN PACIFIC PURSE SEINE FISHERY
AUSTRALIA
40°
30°
20°
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10°
30°
40°
E 120°
130°
140°
150°
160°
170°
180°
170°
160°
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140°
130°
120°
110°
100°
90°
80° W

Figure 1.—Geographical locations of skipjack tuna fisheries in the Pacific Ocean. The dark shaded areas denote surface fisheries; the the light shaded areas denote areas where skipjack tuna have been taken by the Japanese tuna longline fishery. The broken lines indicate the northern and southern limits of the longline fishery.

adequate catch data from mid-oceanic areas using other means, the longline data can be helpful in providing clues to the distribution of skipjack tuna on an ocean-wide basis. The extensive use of longlines geographically (Fig. 1) and in all months of the year makes the data especially useful for this purpose.

Certain characteristics of the longline gear affect the catch and catch data, and these should be cited so that conclusions drawn from the data are viewed in the proper perspective. First, the catches of skipjack tuna by this gear are extremely small. In the years 1962-66, for example, the catch of skipjack tuna in the Japanese commercial tuna longline fishery averaged 1,180 metric tons per year, as compared with an average of 130,000 metric tons caught by the pole-and-line fishery. The smallness of the catch reflects the inefficiency of the gear for taking this species, but, because of the wide areal coverage by this gear, these data should be useful for determining areas of high or low relative abundance.

Second, longlines tend to catch the large fish, although there is evidence that shows this gear to be capable of catching smaller ones also. Miyake (1968) examined the lengths of skipjack tuna caught by longline and by pole and line from the Japanese mother ship *Tenyo Maru* off the Solomon Islands and found that fish taken by longline were significantly larger than those taken by pole and line. Length-composition data for longline-caught skipjack tuna from other areas in the Pacific also show this tendency toward larger fish (Fig. 2), but in the U.S. Trust Territory of the Pacific Islands, for example, the longline catches were composed mainly of fish less than 65 cm, the same group that makes up the bulk of the pole-and-line catch. Longline catches of fish less than 55 cm (3.5 kg) are not uncommon, and the smallest skipjack tuna recorded by scientists of the National Marine Fisheries Service, Honolulu Laboratory measured only 35 cm (Murphy and Shomura 1955).

Third, although the Japanese Government issued regulations in 1963 requiring all tuna fishing vessels to submit copies of their fishing logbooks after each trip, it may be that not all longline-caught skipjack tuna were recorded, since this species is of minor economical importance to the longline fishery and is taken incidentally to other tunas. Failure to do so by these longliners is suspected from the low proportion (expressed as percentages) of skipjack tuna recorded compared to those landed (Table 1). In Table 1, the number of skipjack tuna recorded was converted to weight, using 6.88 kg as the mean weight of skipjack tuna taken on longlines. The mean weight was obtained by converting the mean fish length from four areas of the Pacific Ocean (Fig. 2, panel B), using the length to weight relationship, $\mathrm{Log}_{10} W = -8.342 + 3.368 \mathrm{Log}_{10} L$, developed by the Honolulu Laboratory (the length to weight relationship is based on 1,298 skipjack tuna caught in Hawaiian waters, including both males and females measuring from 32.7 to 87.7 cm). In early years, 1962-64, the proportion of skipjack tuna recorded was extremely low, averaging 21.3%, but in later years, 1965-67, it rose to an average of 60.5%.

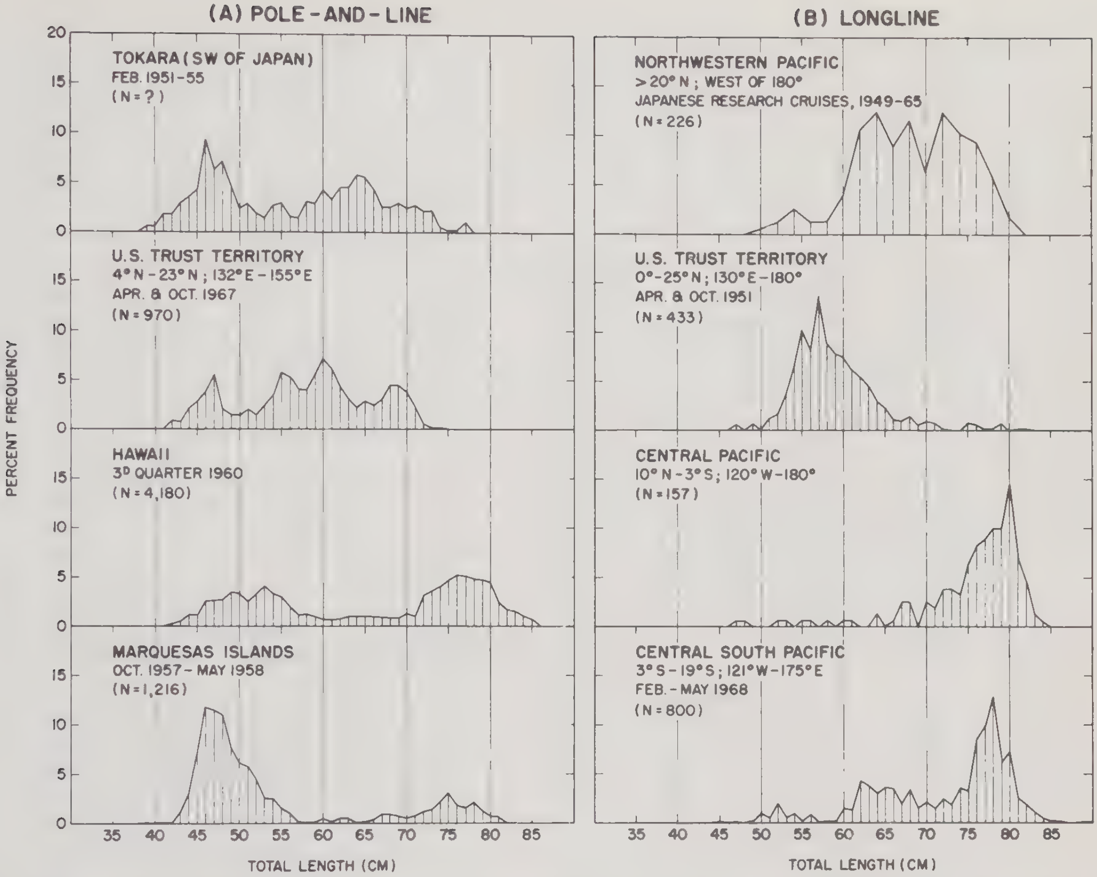


Figure 2.—Length compositions of skipjack tuna taken with pole-and-line and longline gear in various parts of the Pacific Ocean. [Source of data: Panel A—Tokara from Kawasaki (1965); U.S. Trust Territory from Tohoku Regional Fisheries Laboratory (n.d.); Hawaii from Rothschild (1965); Marquesas Islands from Wilson, Nakamura, and Yoshida (1958). Panel B—Northwestern Pacific from Miyake (1968]; U.S. Trust Territory from Murphy and Otsu (1954); central Pacific from Murphy and Shomura (1953, 1955); and Shomura and Murphy (1955); central South Pacific from files NMFS Honolulu Laboratory.]

Table 1.—Estimated ratio of skipjack tuna recorded to skipjack tuna landed in the Japanese longline fishery, 1962-67.

Year	Skipjack recorded[1]		Total skipjack landed[2]	Proportion of skipjack recorded	Average proportion of skipjack recorded
	Number	*Metric ton*	*Metric ton*	*Percent*	*Percent*
1962	20,000	137.6	1,175	11.7	21.3
1963	52,000	357.6	1,082	33.0	
1964	42,000	289.0	1,505	19.2	
1965	105,000	722.4	1,170	61.7	60.5
1966	97,000	667.4	1,175	56.8	
1967	94,000	646.7	1,025	63.1	

[1] Data from Fisheries Agency of Japan, Research Division (1969).

[2] Data from Japan, Ministry of Agriculture and Forestry. Statistics and Survey Division (1963, 1964, 1966, 1967, 1968, 1969).

Miyake (1968) pointed out the possibility that differences between small and large vessels in reporting skipjack tuna catch data could result in geographical bias of the catches, since smaller vessels (20- to 50-ton class) operate only in near coastal waters, whereas larger vessels (>50-ton class) tend to operate farther away (vessel sizes are in gross metric tons). The data, in fact, show that large vessels fished also in areas fished by small vessels. To determine whether there was any difference in recording by vessel size, the quarterly catch rates (skipjack tuna per 1,000 hooks) of small and large vessels in each 5° area fished by both were compared, using the Wilcoxon matched-pair, signed-rank test (Siegel 1956). The tests were made on the premise that the catch rates of small and large vessels fishing in the same area and same quarter would be comparable, so that any large differences would be attributable to differences in recording. Zero catches by both vessel size categories in the same area were excluded, since it could not be established whether these were due to nonrecording or to absence of fish. The tests indicated that the catch rates, and therefore the recording of skipjack tuna caught, were not significantly different (Table 2) between large and small vessels. Hence, it seems unlikely that smaller vessels fishing only in the western Pacific had biased the catches geographically.

Finally, because longliners are fishing for species of tunas other than skipjack, the selection of fishing sites and competition for hooks could affect the catches of skipjack tuna adversely. Any such effect, however, would lose its importance for this study, since in most areas where other tunas are abundant, skipjack are also present, and competition with other tuna species would occur throughout the range of skipjack tuna distribution.

In summary, although the longline catch data for skipjack tuna are affected by certain characteristics of the gear and of the fishery, they appear adequate for my purpose.

Table 2.—Probabilities (two-tailed) of differences in recording skipjack tuna caught on longline between small (20-50) and large (50-200) vessels by quarters (vessel sizes in gross metric tons). The numerals in parentheses indicate vessels having recorded significantly more skipjack tuna: (1) small vessels, (2) large vessels.

Year	First quarter	Second quarter	Third quarter	Fourth quarter
1963	0.3628	—	0.0588	0.8026
1964	0.3370	0.6872	0.0404(1)	0.7948
1965	0.3168	0.4472	0.0602	0.0022(2)
1966	0.8258	0.0014(1)	0.0750	0.8494
1967	0.5156	0.6892	0.2984	0.8966

DISTRIBUTION OF EFFORT

Rothschild (1966) published a summary of effort of the Japanese longline fishery for 1953-63, in which each year's distribution of effort in each 20° area was given as a percentage of that year's total effort. His report shows a gradual eastward expansion of the fishery, and although fishing had approached the coastal waters of North, Central, and South America by 1962, it was not until the following year that adequate coverage was attained in the eastern Pacific. In my study the quarterly effort in numbers of hooks for each 5° area was averaged for 1964-67 and contour lines were drawn at 100,000-hook intervals (Fig. 3).

The figure shows that heavily fished areas are located near Japan in all four quarters, off southeastern Australia in the second and third quarters, and in the eastern Pacific in the first, third, and fourth quarters. Near Japan, the concentration of effort is not only the highest, but remains high throughout the year because the area is accessible to large vessels as well as small ones that make repeated trips during the year. The concentration of high effort shifts from south of Japan in the first and second quarters to east of Japan in the third and fourth quarters, reflecting the seasonal movement of the albacore, *Thunnus alalunga*, (Van Campen 1960) and the bigeye tuna, *T. obesus*, which are the main species of tunas fished by the longliners in this region. Both the route and time of the shift generally agree with that of skipjack tuna caught by surface gear within the area (Kimura 1949). The heavy effort off Australia in the second, third, and perhaps the fourth quarters is expended mainly for southern bluefin tuna, *T. maccoyii*, and albacore (appendix figures 2 and 5; Fisheries Agency of Japan, Research Division, 1967a, 1967b, 1968, 1969); while in the eastern Pacific, fishing is concentrated off the northern coast of South America in the first and fourth quarters for bigeye tuna and striped marlin, *Tetrapturus audax*, and off Baja California in the third and fourth quarters for striped marlin (Kume and Joseph 1969).

The effort is more evenly distributed, though at lower levels, over the equatorial region between lat. 20°N and 20°S. Moderate fishing prevails in an almost continuous band along the equator from the eastern to the western Pacific for the greater part of the year. This band is interrupted over a relatively short distance only during the last quarter.

RELATIVE ABUNDANCE OF SKIPJACK TUNA

Distribution of Catch Per Unit Effort

To show the relative abundance of skipjack tuna taken by longlines, the catch per unit effort (CPUE), expressed here as number of skipjack tuna caught per 1,000 hooks per quarter in all 5° areas fished, was calculated and plotted for the 4 yr. Because of skewed distribution of the catches, the geometric mean was calculated for each quarter's catches and contour lines were drawn to emphasize high-CPUE areas (Figs. 4-7).

The distribution of CPUE (Figs. 4-7) indicates widespread occurrence of skipjack tuna in the Pacific Ocean. The north-south distribution is expanded latitudinally in the west due largely to the greater poleward dispersion there of warm water inhabited by the tunas. The distribution is generally narrow in the eastern Pacific where cooler waters flowing toward the equator tend to restrict the poleward dispersion of the skipjack tuna. The predominance of zero-catch areas (indicated by -'s) at both the northern and southern fringes during most quarters assured that fishing had occurred over the whole range of adult skipjack tuna distribution.

The contoured areas of above-average CPUE appear either singly or in clusters in various parts of the Pacific. To facilitate the discussion the Pacific Ocean was partitioned into western (A), central (B), and eastern (C) regions (Figs. 4-7). Boundary lines were drawn as close as possible along lines of apparent breaks in the distribution of above-average CPUE areas.

In region A, north of the equator, high catch rates occurred sporadically; in 1964, for example, they occurred in all four quarters, but in 1965-67 in only two quarters. The above-average CPUE cells there were small and seemed to be associated with seasons and areas: in the second and third quarters off Japan, and in the first, second, and fourth quarters east of the Philippine Islands. South of the equator high-CPUE cells generally occurred off northeastern Australia in the fourth and first quarters and off southeastern Australia in the second and third quarters. Cells of high CPUE, however, seemed less consistent from year to year off Australia than in the adjacent region B. In 1966, for example, high CPUE occurred only in the first quarter, and in both 1964 and 1965 they were not as extensive as in 1967. Here as in other regions interyear differences probably relate to changes in gross oceanographic conditions.

In region B, south of latitude approximately 10°N, the high-CPUE cells were most extensive and persistent throughout the year. In most quarters, these cells straddled the equator, but in some they were displaced slightly to the south. The cells also expanded and contracted, or were displaced to the east or west seasonally, but without any obvious regularity. The number and locations of these cells varied from quarter to quarter and from year to year. Of particular interest about the area is that it is also where skipjack tuna larvae have been found in abundance (see later discussion), and it may well be the main spawning grounds of skipjack tuna of the central and eastern Pacific.

North of lat. 10°N, the high-CPUE cells occurred in the Hawaiian to Leeward Islands area and in the Wake to Marcus Island area west of long. 180°. These high-CPUE cells generally occurred farther to the north in the fourth and first quarters than they did in the second and third quarters. The cells in the Wake-Marcus area were not consistent from year to year; the CPUEs were high in the fourth quarter in 1964 and first quarter in 1965, nil in 1966, and high in the first and second quarters of 1967. In the Hawaiian area, the high-CPUE cells were often contiguous with the large high-CPUE area straddling the equator. This occurred in the first quarter 1964, second, third, and fourth quarters 1965, and second and fourth quarters 1966. The contiguity of high-CPUE cells in Hawaiian waters with the large equatorial high-CPUE cell in the east-central Pacific seems to be associated with the annual surface catches of the Hawaiian pole-and-line fishery. In 1964, 1966, and 1967, when the high-CPUE cells in the two areas were contiguous in fewer than two quarters, the Hawaiian pole-and-line catches were below the 1952-70 long-term average catch of 4,311 metric tons, in 1965, however, when the high-CPUE cells were contiguous in three successive quarters, the Hawaiian pole-and-line catch was 7,329 metric tons, the highest in the history of the fishery and 70% above the long-term average catch.

In region C, south of the equator, the high-CPUE cells were not extensive, but were persistent throughout most of the year. During some quarters these cells were contiguous with those of region B; in others they were discrete and were found either further south or east. North of the equator high-CPUE cells generally occurred near the equator adjacent to and often as part of the central Pacific (region B) high-CPUE area. They appeared more consistently in the first and fourth quarters. In waters closer to Mexico and California, the cells of high CPUE occurred in all 4 yr but they were not all large or equally close to shore. Prominent high-CPUE cells nearshore occurred only in the fourth quarter of 1965 and in the third and fourth quarters of 1967. In both years, the skipjack tuna landings in the eastern Pacific surface fishery were high; in fact the 1967 catch was the highest ever recorded there.

In region C north of the equator, particularly around the southern half of Baja California in waters bounded by lat. 20° and 30°N and long. 110° and 120°W, the Japanese longliners also fish for swordfish, *Xiphias gladius*. This fishing is done at night, and both the gear change and the time of fishing adversely affect the capture of skipjack tuna. According to Kume and Joseph (1969, Fig. 4), night fishing in the area accounted for 21% of the longline effort (in sets) in 1964-66, mostly (about 75%) in the fourth quarter. If the night fishing effort is deducted from the total longline effort, the CPUE of skipjack tuna in this area will be higher. The resulting changes in CPUE, however, will not materially change the contours as shown in Figures 4-7.

Salient Features in the Distribution of Catches and Catches Per Unit Effort

Several features stand out in the distributions of catches and cells of high CPUE in the Pacific. The first is the irregular north-south displacement of boundaries of skipjack tuna catches (Fig. 8). The northern and southern boundaries do not move in unison with respect to seasons, nor uniformly across the ocean. In the western Pacific (west of long. 180°), the maximum northward displacement of the northern boundary occurs in the third quarter and maximum southward displacement in the second quarter. To the east of long. 180°, however, the maximum northward displacement of the northern boundary occurs in the fourth quarter and the maximum southward displacement occurs in the third and fourth quarters. Such differences also are evident in the shifting of the southern boundary in the eastern, central, and western Pacific.

Irregular north to south movement is indicated also in the high-CPUE cells. In the Hawaiian to Leeward Islands area, the high-CPUE cells occur throughout the year, with the maximum southward displacement occurring in the second quarter. In Philippine and Japanese waters, the northward displacement of high-CPUE cells occurs in the second and third quarters and the southward displacement in the fourth and first quarters.

The second feature is the apparent disparity between the high catch areas of the longline fishery and those of the surface fisheries. The bulk of the skipjack tuna production in the Pacific comes from the northwestern (Japanese pole and line) and the eastern (United States purse seine) surface fisheries, yet the high-CPUE areas in both places are not as extensive as one would expect. This is likely due 1) to gear selectivity, longlines fishing deeper and being more effective on large fish and 2) to the relative absence of large fish near the surface in these areas. The predominance of younger fish in the two surface fisheries has been shown by Kawasaki (1965) and Broadhead and Barrett (1964). In the Hawaiian Islands area, where large skipjack tuna are better represented in the surface fishery (Rothschild 1965), the disparity between the longline and surface fishery catches is less evident. In fact, as previously mentioned, there may be some association there between the longline and surface pole-and-line catches.

The third feature is the extent and persistence of high CPUE in the central equatorial area (region B, south of lat. 10°N), where presently there is only a small surface fishery in Tahiti (Brun and Klawe 1968). The high-CPUE areas there not only persist throughout the year, but are more extensive than all other high-CPUE areas combined during most quarters. The general location of this high-CPUE area is of particular

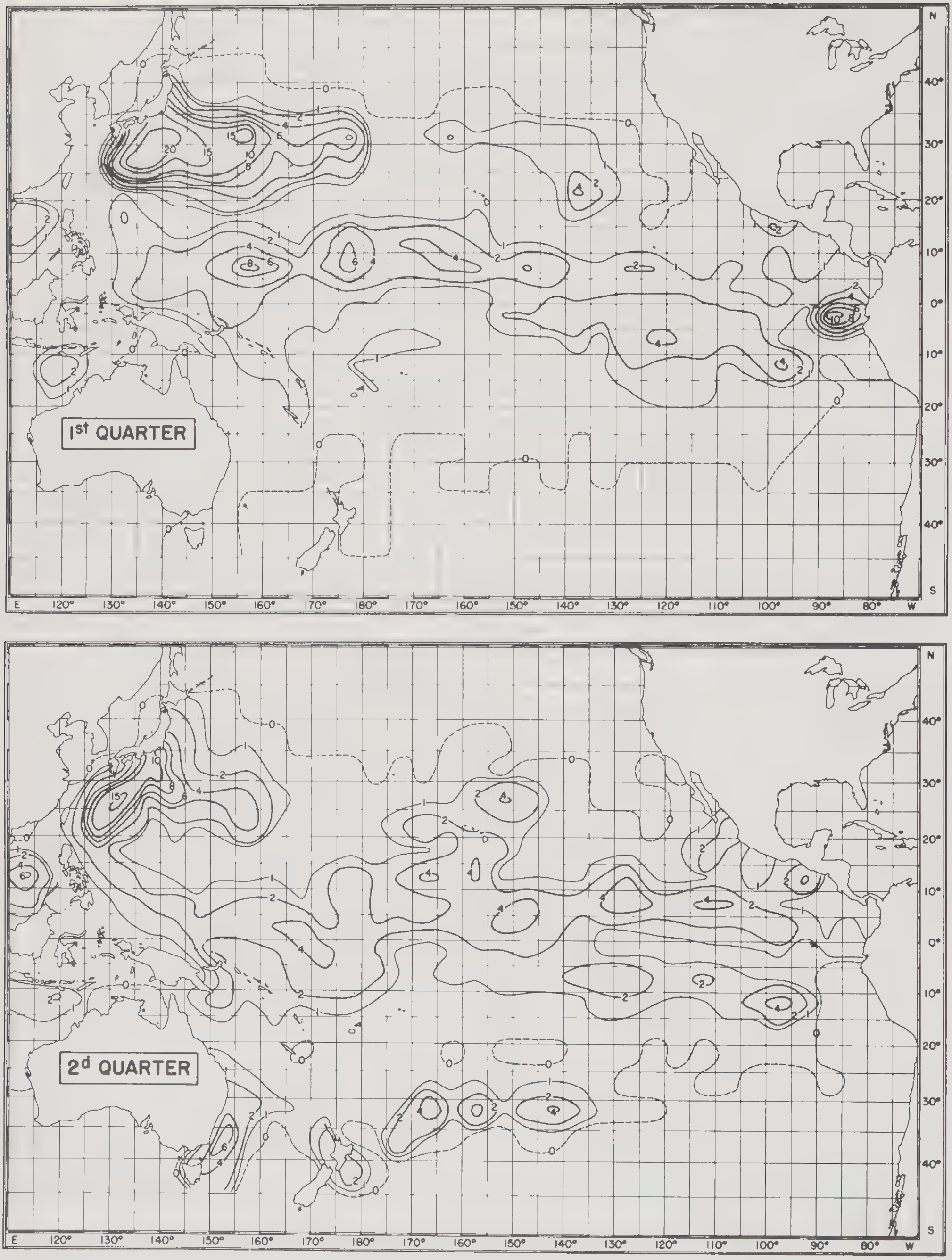
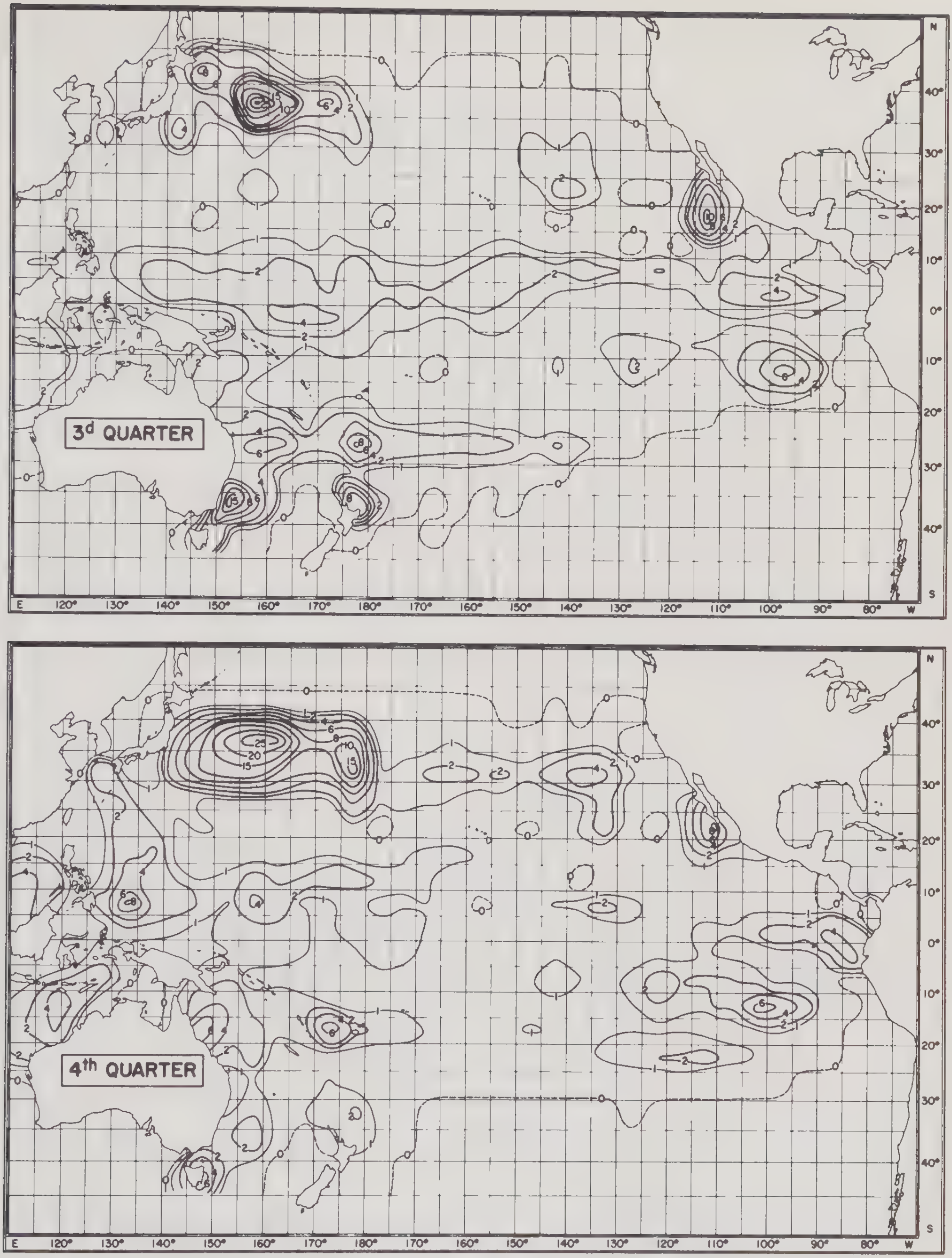

1st QUARTER
2d QUARTER
E
120°
130°
140°
150°
160°
170°
180°
170°
160°
150°
140°
130°
120°
110°
100°
90°
80°
W
N
40°
30°
20°
10°
0°
10°
20°
30°
40°
S

Figure 3.—Average quarterly effort expended by the Japanese tuna longline fishery, 1964-67.


3d QUARTER
4th QUARTER
E
120°
130°
140°
150°
160°
170°
180°
170°
160°
150°
140°
130°
120°
110°
100°
90°
80°
W
N
40°
30°
20°
10°
0°
10°
20°
30°
40°
S

The contour lines are drawn at intervals of 100,000 hooks. The broken lines denote limits of fishing.

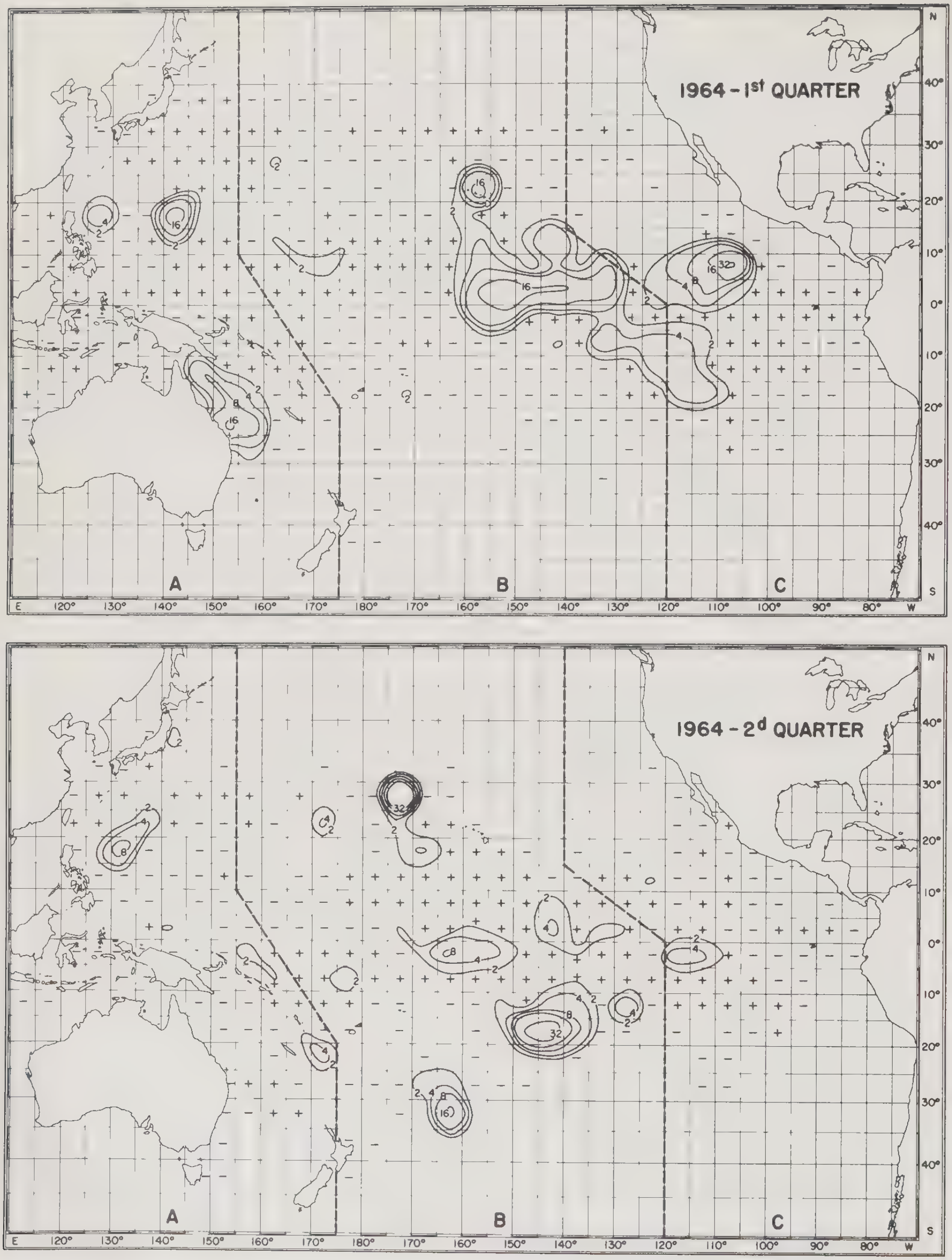
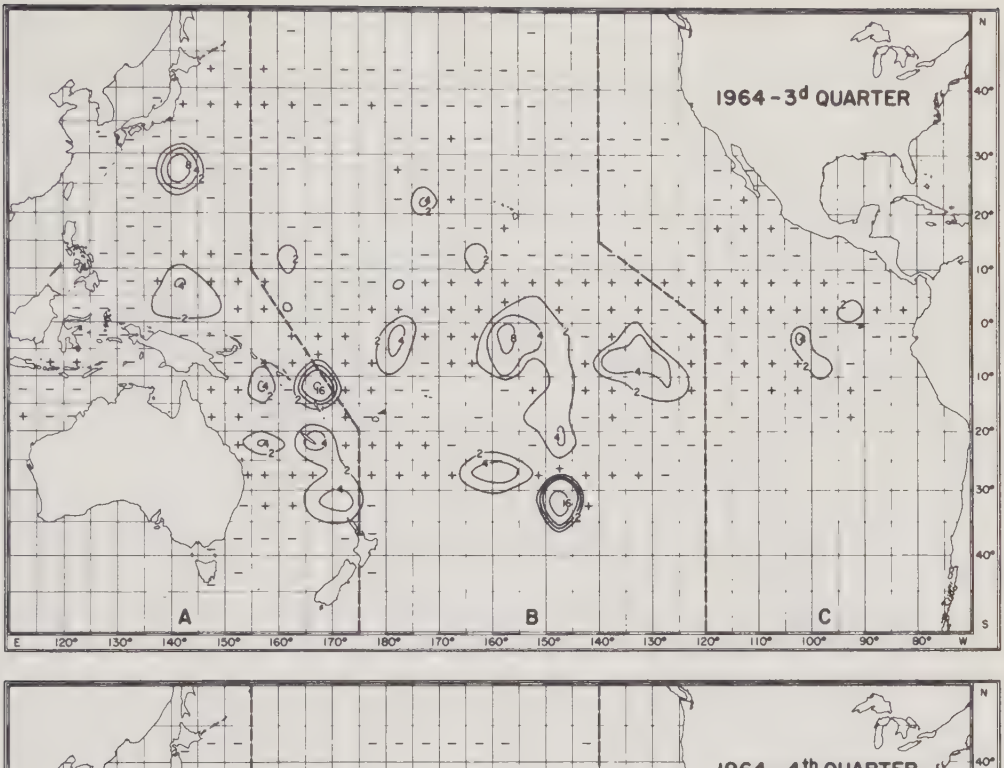

1964 - 1st QUARTER
1964 - 2d QUARTER
A
B
C
N
S
E
W
120°
130°
140°
150°
160°
170°
180°
170°
160°
150°
140°
130°
120°
110°
100°
90°
80°
40°
30°
20°
10°
0°
10°
20°
30°
40°
2
4
8
16
32

Figure 4.—Distribution of catch per unit effort of skipjack tuna taken by the Japanese tuna longline fishery, 1964. The contour lines are drawn at intervals of 2, 4, 8, 16, etc., times the mean catch per 1,000 hooks per quarter per 5° area fished. The symbols + and − represent CPUEs less than twice the mean and no skipjack tuna caught or recorded, respectively. (The small circles are contour lines, not


1964 - 3d QUARTER
1964 - 4th QUARTER
A
B
C
E
120°
130°
140°
150°
160°
170°
180°
170°
160°
150°
140°
130°
120°
110°
100°
90°
80°
W
N
40°
30°
20°
10°
0°
10°
20°
30°
40°
S

ciphers.). Mean CPUE for each 5° area fished; 1st quarter, 0.118; 2d quarter, 0.153; 3d quarter, 0.138; 4th quarter, 0.104. Regions A, B, and C are arbitrary partitions to facilitate the discussion.

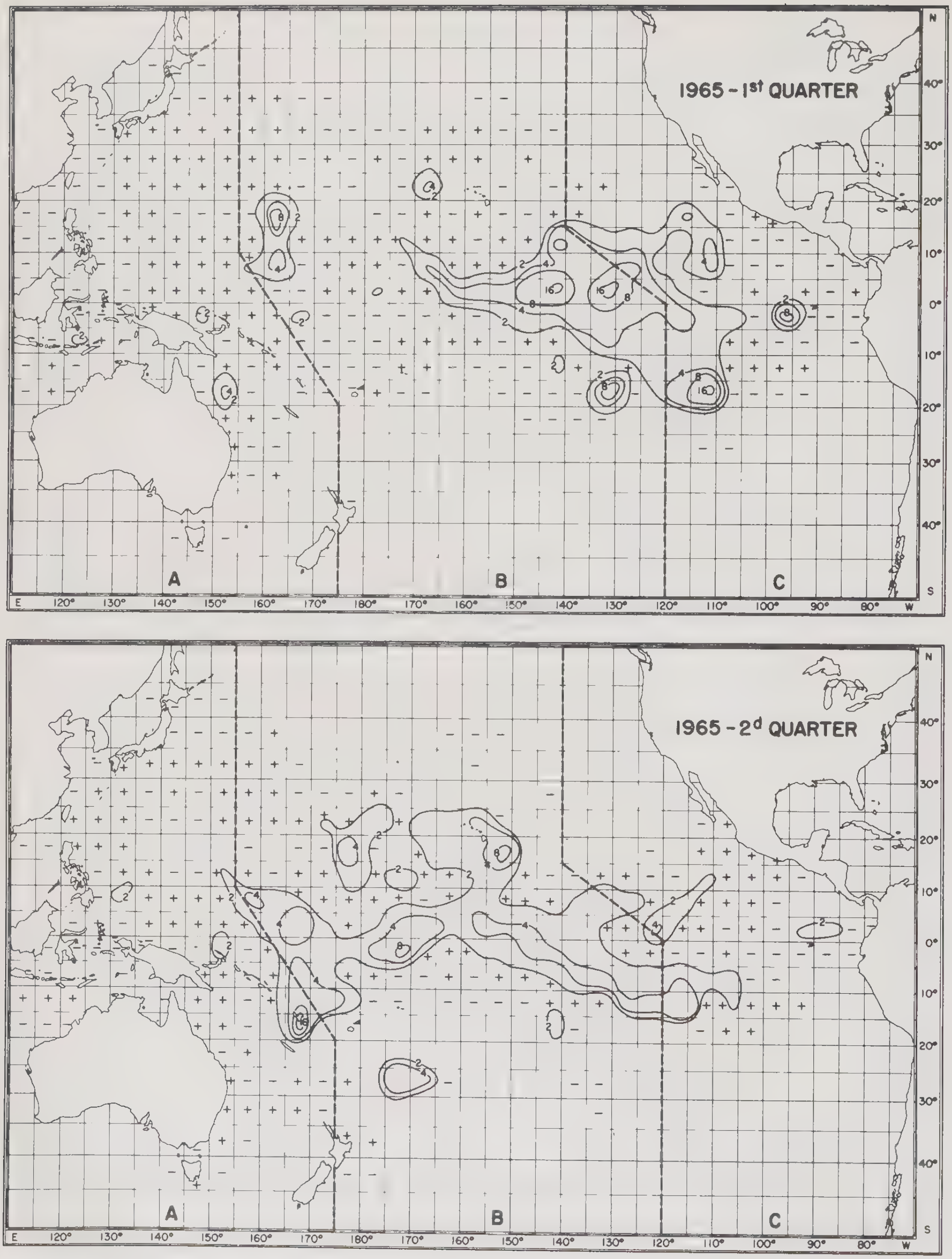
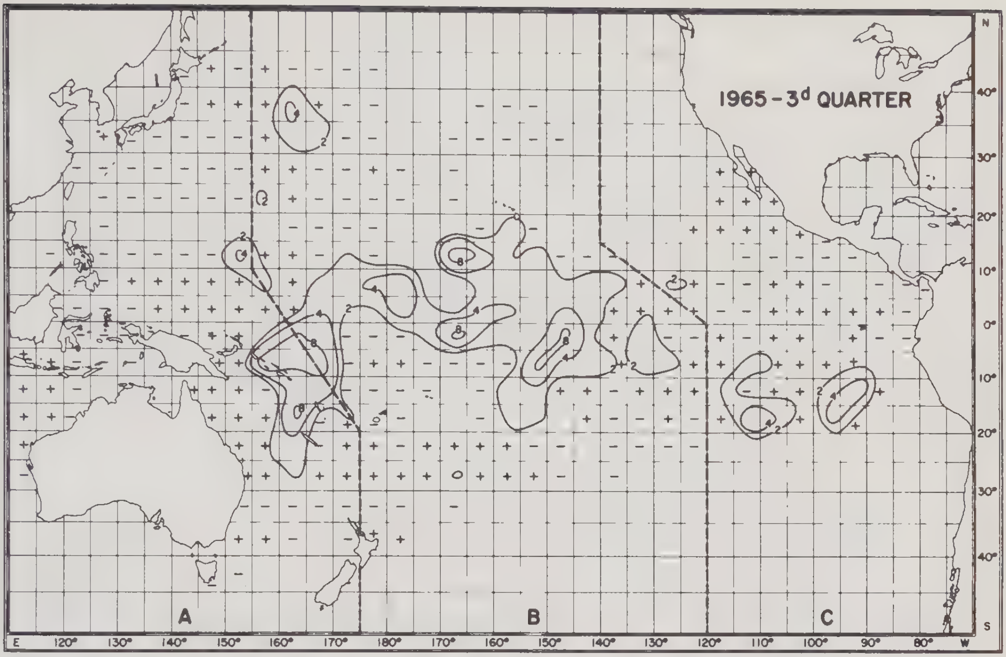
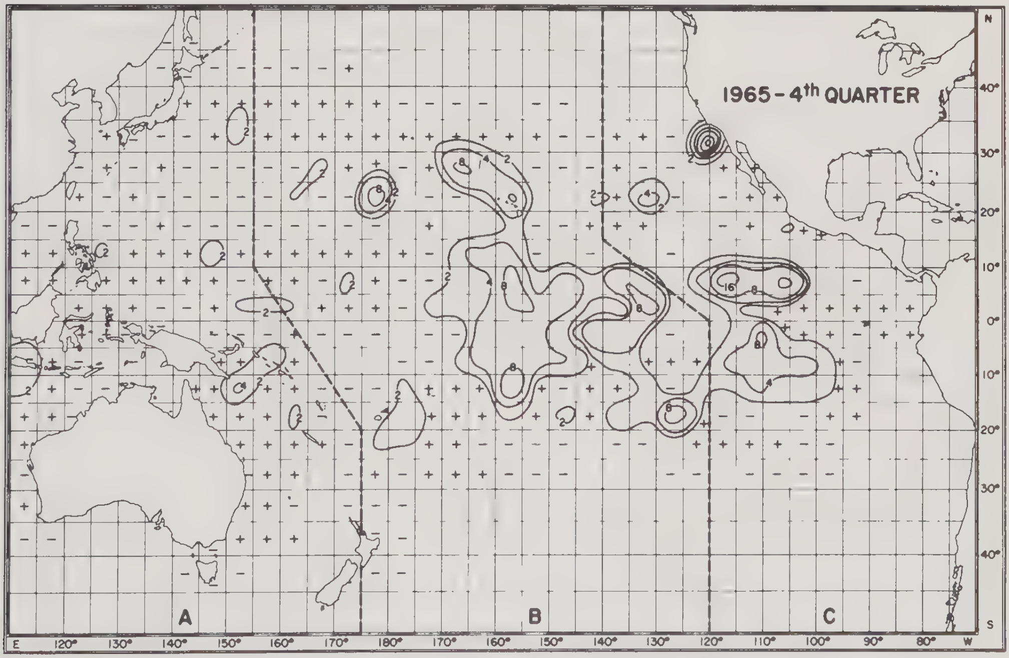

1965 - 1st QUARTER
1965 - 2d QUARTER
A
B
C
N
S
E
W
120°
130°
140°
150°
160°
170°
180°
170°
160°
150°
140°
130°
120°
110°
100°
90°
80°
40°
30°
20°
10°
0°
10°
20°
30°
40°

Figure 5.—Distribution of catch per unit effort of skipjack tuna taken by the Japanese tuna longline fishery, 1965. The contour lines are drawn at intervals of 2, 4, 8, 16, etc., times the mean catch per 1,000 hooks per quarter per 5° area fished. The symbols + and − represent CPUEs less than twice the mean and no skipjack tuna caught or recorded, respectively. (The small circles are contour lines, not


1965 - 3d QUARTER
A
B
C
N
S
E
W
40°
30°
20°
10°
0°
10°
20°
30°
40°
120°
130°
140°
150°
160°
170°
180°
170°
160°
150°
140°
130°
120°
110°
100°
90°
80°


1965 - 4th QUARTER
A
B
C
N
S
E
W
40°
30°
20°
10°
0°
10°
20°
30°
40°
120°
130°
140°
150°
160°
170°
180°
170°
160°
150°
140°
130°
120°
110°
100°
90°
80°

ciphers.) Mean CPUE for each 5° area fished; 1st quarter, 0.219; 2d quarter, 0.310; 3d quarter, 0.241; 4th quarter, 0.209. Regions A, B, and C are arbitrary partitions to facilitate the discussion.

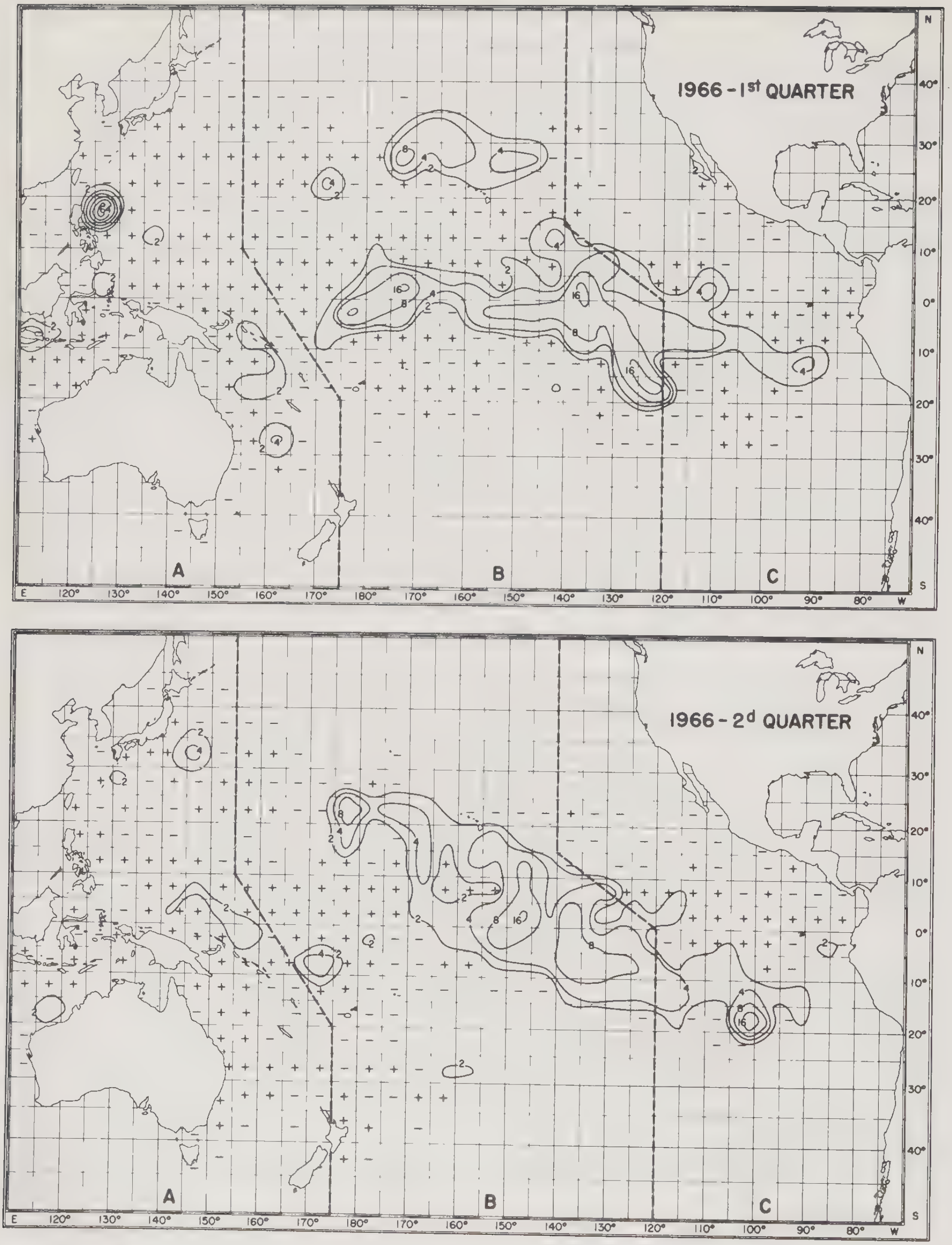
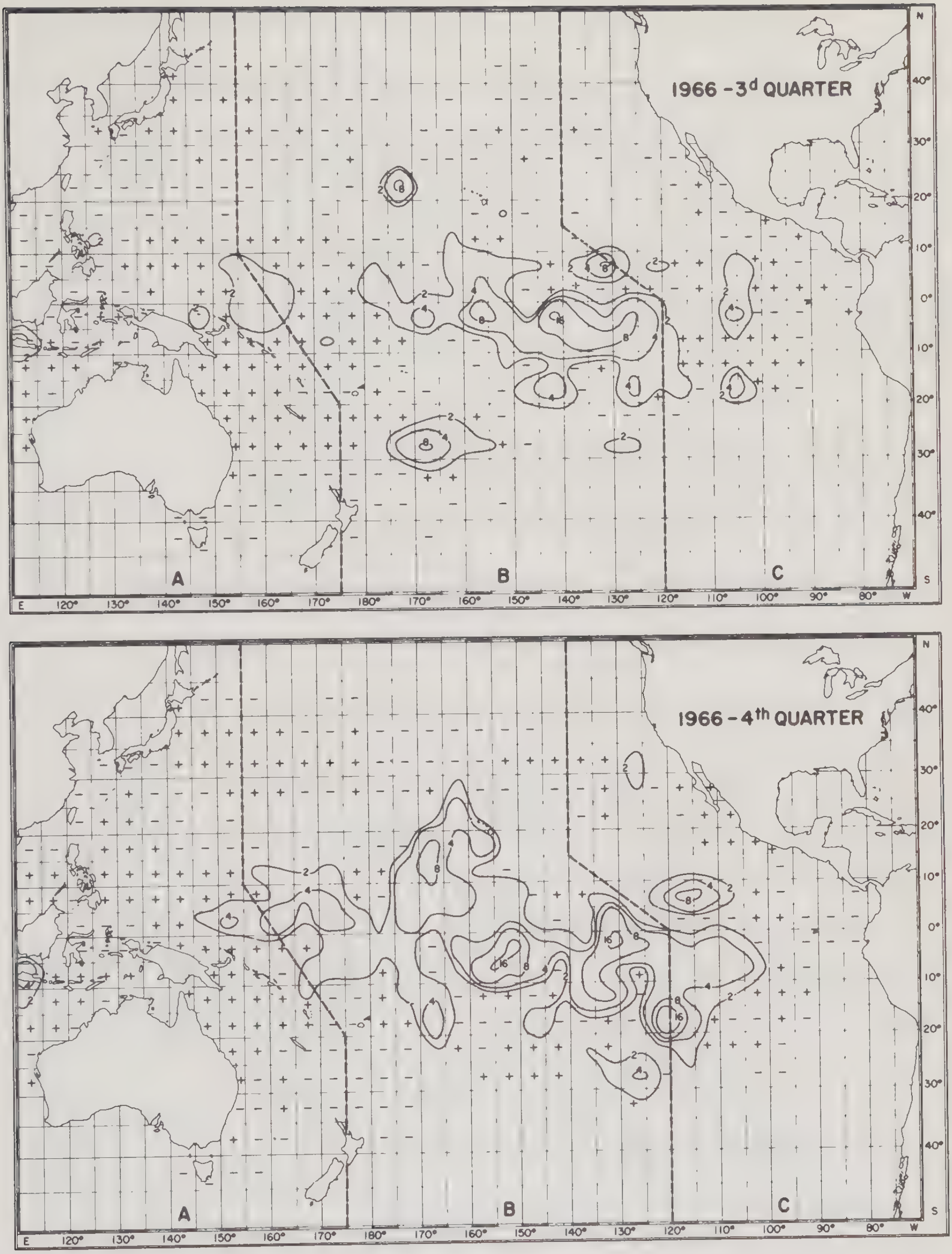

1966 - 1st QUARTER
1966 - 2d QUARTER
A
B
C
N
S
E
W
40°
30°
20°
10°
0°
10°
20°
30°
40°
120°
130°
140°
150°
160°
170°
180°
170°
160°
150°
140°
130°
120°
110°
100°
90°
80°
2
4
8
16

Figure 6. - Distribution of catch per unit effort of skipjack tuna taken by the Japanese tuna longline fishery, 1966. The contour lines are drawn at intervals of 2, 4, 8, 16, etc., times the mean catch per 1,000 hooks per quarter per 5° area fished. The symbols + and − represent CPUEs less than twice the mean and no skipjack tuna caught or recorded, respectively. (The small circles are contour lines, not


1966 - 3d QUARTER
A
B
C
1966 - 4th QUARTER
A
B
C
N
S
E
W
40°
30°
20°
10°
0°
10°
20°
30°
40°
120°
130°
140°
150°
160°
170°
180°
170°
160°
150°
140°
130°
120°
110°
100°
90°
80°
2
4
8
16

ciphers.) Mean CPUE for each 5° area fished: 1st quarter, 0.241; 2d quarter, 0.206; 3d quarter, 0.208; 4th quarter, 0.237. Regions A, B, and C are arbitrary partitions to facilitate the discussion.

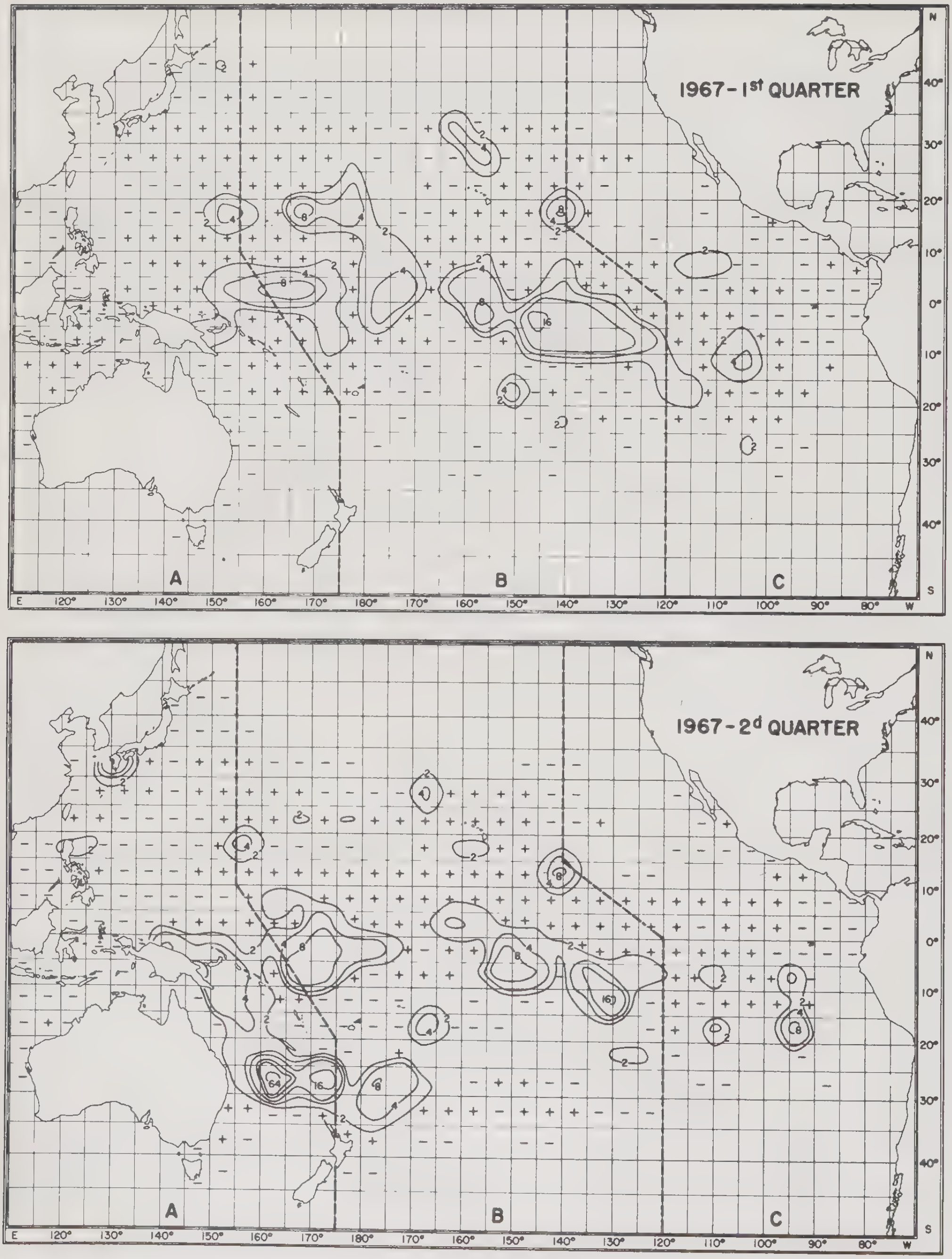
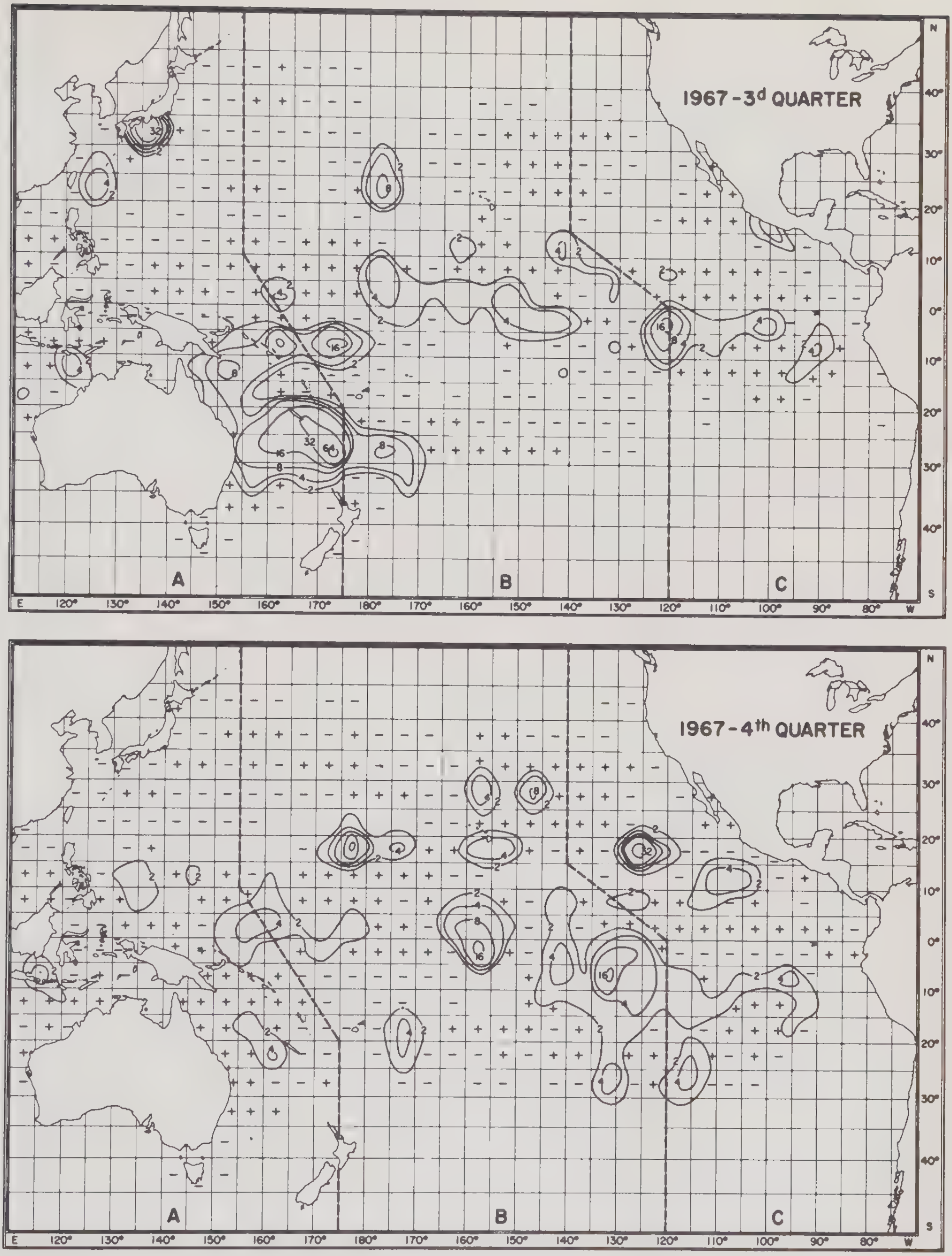

1967-1st QUARTER
1967-2d QUARTER
A
B
C
N
S
E
W
120°
130°
140°
150°
160°
170°
180°
170°
160°
150°
140°
130°
120°
110°
100°
90°
80°
40°
30°
20°
10°
0°
10°
20°
30°
40°
2
4
8
16
64

Figure 7.—Distribution of catch per unit effort of skipjack tuna taken by the Japanese tuna longline fishery, 1967. The contour lines are drawn at intervals of 2, 4, 8, 16, etc., times the mean catch per 1,000 hooks per quarter per 5° area fished. The symbols + and – represent CPUEs less than twice the mean and no skipjack tuna caught or recorded, respectively. (The small circles are contour lines, not


1967-3d QUARTER
A
B
C
N
S
E
W
120°
130°
140°
150°
160°
170°
180°
170°
160°
150°
140°
130°
120°
110°
100°
90°
80°
40°
30°
20°
10°
0°
10°
20°
30°
40°
1967-4th QUARTER
A
B
C

ciphers.) Mean CPUE for each 5° area fished; 1st quarter, 0.233; 2d quarter, 0.190; 3d quarter, 0.169; 4th quarter, 0.205. Regions A, B, and C are arbitrary partitions to facilitate the discussion.

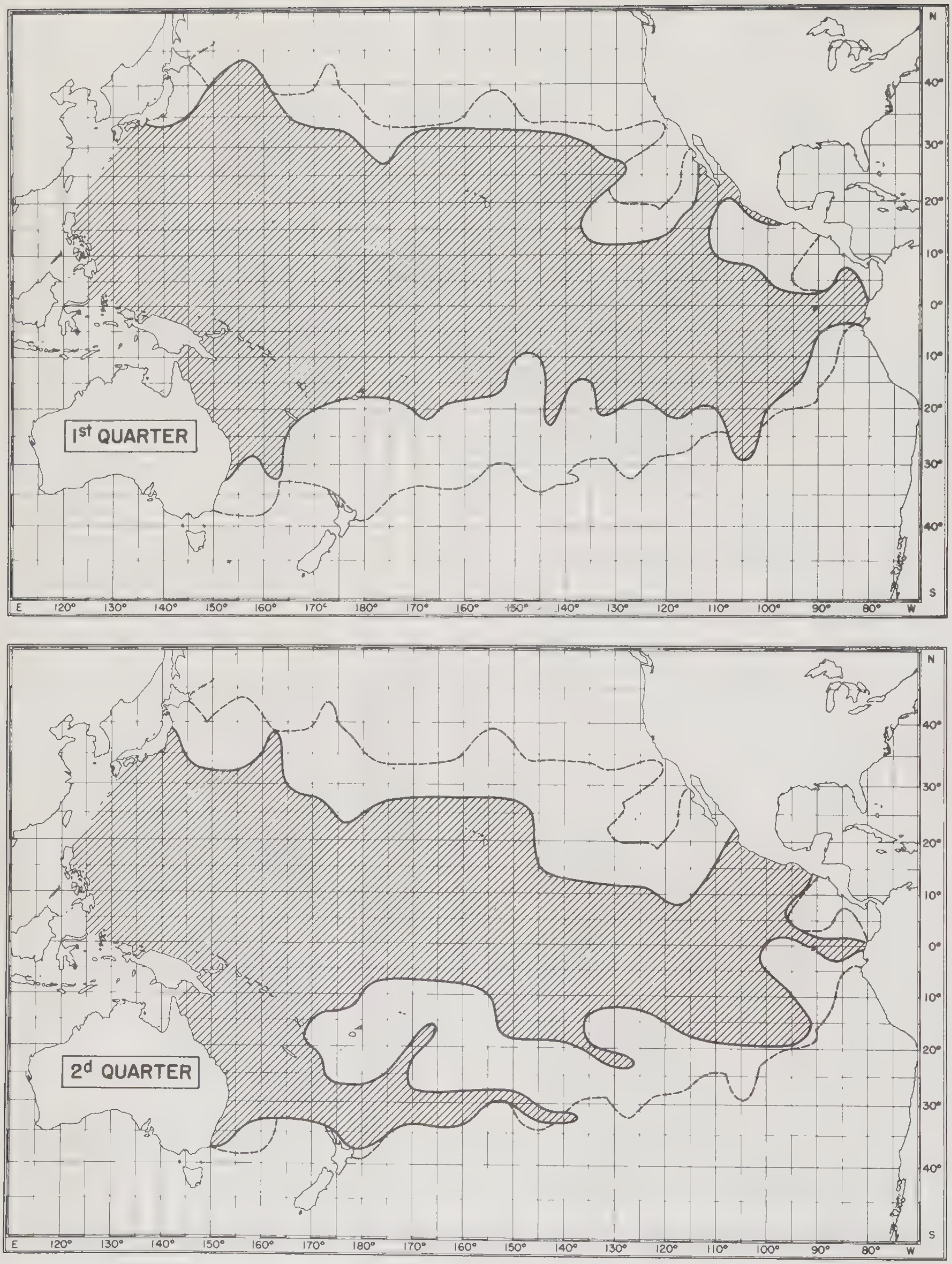
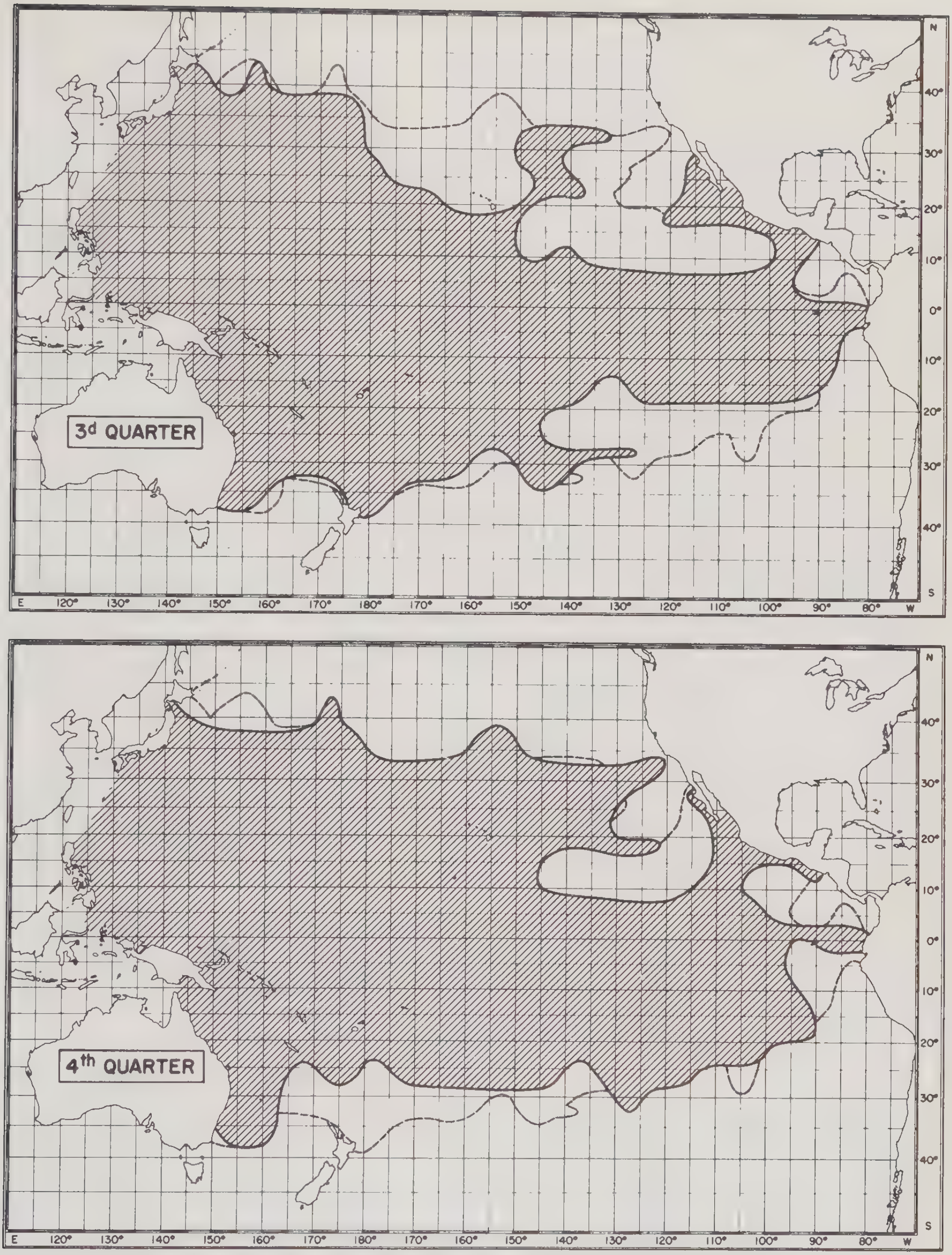

1st QUARTER
2d QUARTER
N
40°
30°
20°
10°
0°
10°
20°
30°
40°
S
E
120°
130°
140°
150°
160°
170°
180°
170°
160°
150°
140°
130°
120°
110°
100°
90°
80°
W

Figure 8.—Outlines of the northern and southern boundaries of skipjack tuna caught in the Japanese tuna longline


3d QUARTER
4th QUARTER
N
S
E
W
40°
30°
20°
10°
0°
10°
20°
30°
40°
120°
130°
140°
150°
160°
170°
180°
170°
160°
150°
140°
130°
120°
110°
100°
90°
80°

fishery, 1964-67, by quarters (shaded area). The broken lines denote the maximum range in the four quarters.

interest since it corresponds with the central equatorial spawning grounds from which the skipjack tuna taken in the eastern Pacific fishery is assumed to originate (Kawasaki 1965; Rothschild 1965; Williams 1972).

Adult-Larvae Relationship in the Equatorial Pacific

As discussed previously, the tuna longline tends to catch the larger tunas, and so a major portion of the skipjack tuna taken by this gear consists of the larger, more mature fish. Consequently, in areas where the longline CPUE is high, especially in waters suitable for spawning, the concentrations of larvae also should be high. To confirm this probable relationship and to delineate the spawning area, the relative abundance of adults in 20° sectors along the equator was compared with that of the larvae.

Numerous larval net tows have been made in the Pacific over the past 25-30 yr, but this coverage of the ocean with respect to time and space has not been as intensive as that by the longline. Moreover, larval net tows made in all sections of the Pacific were not uniform with respect to towing methods and net sizes. In the eastern Pacific, where net tows were made principally by the Inter-American Tropical Tuna Commission, the Scripps Institution of Oceanography, and the National Marine Fisheries Service, La Jolla Laboratory, 30-min surface tows and oblique tows to 140, 300, and 400 m were made with a 1-m net equipped with a flowmeter (Klawe 1963); in the central Pacific, where net tows were made by the National Marine Fisheries Service, Honolulu Laboratory, 30-min surface tows and oblique tows to 60, 140, and 200 m were made with a similar net (Matsumoto 1958; Strasburg 1960); and in the western Pacific, where net tows were made by the Far Seas Fisheries Research Laboratory, a 2-m net without flowmeter was towed horizontally for 20 min at the surface and at depths of 20-30 and 50 m at vessel speeds of 1.03 m/s or 2 knots (Ueyanagi 1969).

Of all the tows made, only the surface tow was commonly used in all three areas. Consequently, abundance of skipjack tuna larvae across the Pacific was determined only from catches in surface tows after the following adjustments had been made:

1. To eliminate variability resulting from diel vertical migration, a prominent characteristic of the skipjack tuna larvae (Matsumoto 1958; Ueyangi 1969), only surface night tows were used.
2. To obtain comparable coverage across the ocean, the areas from which tows were compared were limited to 20° longitudinal sectors along the equator between lat. 00° and 20°N in the western; between lat. 10°S and 20°N in the central; between lat. 07°S and 15°N in the east-central; and between lat. 04° and 15°N in the eastern Pacific.
3. To reduce seasonal variability in the catches, only tows made in spawning months were considered. These included April through September in areas between lat. 10° and 20°N and all months of the year in areas between lat. 10°N and 10°S (Matsumoto 1958; Strasburg 1960; Klawe 1963; Ueyanagi 1969).
4. To compensate for differences in net size and duration of tow, the catches in all areas were adjusted to a standard tow that strained 1,454 m^3 of water, a volume equivalent to that strained by a 1-m net towed at 1.03 m/s for 30 min. The adjustment was made by applying a conversion factor (i.e., the ratio of standard volume to average volume of water strained in the central Pacific do not constitute a single, homogeneous volume to estimated volume of water strained in the western Pacific) to the catches in the three areas. Although the adjustment is rough, the adjusted catch values for all quarters for the years 1950-67 (Table 3) appear reasonable.

A plot of adjusted catch rates (Fig. 9) indicates that between lat. 20°N and 10°S, skipjack tuna larvae were most abundant in the central Pacific between long. 140°W and 160°E, with the peak in the sector between long. 160°W and 180°. Larvae were less abundant in the areas east of long. 140°W and west of long. 160°E. The

Table 3.—Catch rates of larval skipjack tuna in night surface tows across the Pacific Ocean.

Longitude	Latitude	Quarter sampled	Net diameter	Duration of tow	Number of tows	Total larvae	Conversion factor	Adjusted catch	Adjusted larvae per tow
			Meter	*Minutes*		*Number*			
80°-100°W	4°-15°N	I, II	1	30	33	7	[2]1.836	12.85	0.39
100°-120°W	10°-15°N	II	1	30	10	11	[2]1.836	20.20	1.63
100°-120°W	0°-7°S	I	1	30	12	19	[3]0.827	15.71	
120°-140°W	10°S-10°N	I, IV	1	30	21	42	[3]0.827	34.73	1.65
140°-160°W	10°S-20°N	I, III	1	30	32	239	[3]0.827	195.18	6.10
160°W-180°	10°S-20°N	I, II, III	1	30	45	389	[3]0.827	321.70	7.15
160°E-180°	10°S-20°N	I, III	1	30	6	45	[3]0.827	37.22	4.94
160°E-180°	10°S-20°N	II, IV	2	20	44	560	[4]0.375	210.00	
140°-160°E	10°S-20°N	II, III, IV	2	20	112	562	[4]0.375	210.75	1.88
120°-140°E	0°-20°N	II, IV	2	20	141	581	[4]0.375	217.88	1.54

[1] Conversion factor is the ratio of standard to average volume of water strained. Standard volume used was 1,454 m^3.

[2] Computed from average volume of 792 m^3 from 62 tows in the eastern Pacific. (Data from Klawe 1963.)

[3] Computed from average volume of 1,759 m^3 from 289 tows in the central Pacific. (Data from BCF Biological Laboratory, Honolulu files and Strasburg 1960.)

[4] Computed from estimated volume of 3,878 m^3, the volume strained at a given towing speed of 1.03 m/s (2 knots) in the western Pacific. (Catch data from Ueyanagi 1969.)

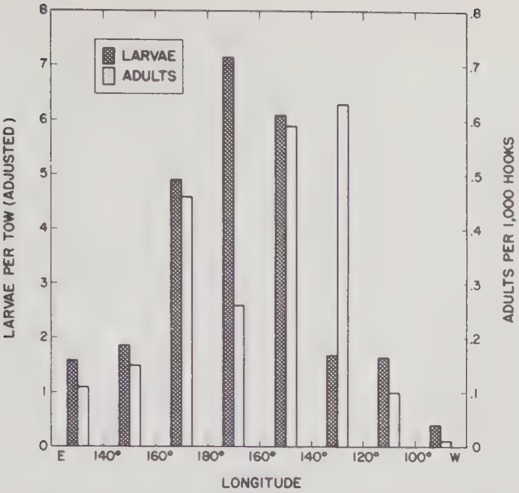


Figure 9.—Catch rates of skipjack tuna larvae and adults across the Pacific Ocean between lat. 10°S and 20°N.

extremely low catch rate in the eastern Pacific may be due partly to incomplete sampling coverage near the equator and to the lack of sampling south of the equator. Even with comparable sampling in these areas, however, it seems unlikely that the catch rate would have been as high as in the central Pacific.

The catch rates (catch per 1,000 hooks fished) of adult skipjack tuna taken by the longline in areas and quarters similar to those of the larvae showed a comparable trend (Fig. 9). The catch rates were low in the eastern and western Pacific and high in the central Pacific. The only apparent difference between the two plots was the slight dislocation of the peaks. The lack of larval net tows for the years 1964-67 across the Pacific, however, does not permit statistical testing of the catch trends. Nevertheless, the similarity between the high CPUE of adult skipjack tuna and the high larval density in the central equatorial Pacific, seems to support the assumptions by Kawaski (1965), Rothschild (1965), and Williams (1972) that the central equatorial spawning ground is the source of the skipjack tuna taken in the eastern Pacific fishery.

MOVEMENT OF SKIPJACK TUNA IN THE PACIFIC

Past Studies on Movemnt of Skipjack Tuna

A number of studies have been made on the population structure and movement of skipjack tuna in various sections of the Pacific. Fujino (1970a, 1970b) has proposed the existence of two genetically distinct subpopulations of skipjack tuna in the western North Pacific, separated by a line passing through the Caroline-Mariana-Bonin archipelagoes. In a more recent study, Fujino (1972) has extended this boundary line southward along long. 170°E from the Equatorial Countercurrent to the area east of New Caledonia and through the Tasman Sea and has proposed a model of population structure and migration for the entire area (Fig. 10). He proposed 1) that fish of the western Pacific subpopulation in the northern hemisphere remain within the Philippine Sea and areas of the Caroline Islands in the northern winter and range eastward to about long. 165°E in the northern summer; 2) that in both northern and southern hemispheres there are two spawning groups (summer, A; winter, B) which behave differently from each other without diversification in genetic composition; and 3) that the two groups (A and B) migrate in different proportions by age and area, with intermingling taking place between northern and southern A groups and between northern and southern B groups at the time of spawning and during the larval stages.

Kawasaki (1965) proposed that the skipjack tuna in the eastern and western North Pacific fishery originated from fish spawned in the central equatorial region between long. 160°E and 140°W. He (1972) subsequently modified this view by extending the principal spawning area westward to long. 120°E and, as a result of Fujino's work, recognized the possibility of a separate western Pacific subpopulation.

Rothschild (1965) suggested that skipjack tuna in the central Pacific do not constitute a single, homogeneous population unit; that they originate in three possible zones—Hawaiian, equatorial, and Marquesan; that the Marquesan zone does not contribute significant numbers to the skipjack tuna taken in the eastern Pacific; and that the eastern Pacific skipjack tuna originate either in the Hawaiian or equatorial zone. He further proposed that the potential recruits to the eastern Pacific are "split" into a northern group that enters the Mexican fishery and a southern group that enters the South American fishery, citing as a possible splitting mechanism the warm-water cell (surface temperature >28°C) in the vicinity of lat. 15°N off the central American coast.

Fink and Bayliff (1970) discussed the migration of skipjack tuna in the eastern Pacific based on tagging results. Their findings indicated that fish in the northern group (north of lat. 15°N) entered the fishery in April through the Revilla Gigedo Islands and moved inshore and northward along the coast of Baja California generally to lat. 30°N in the third quarter. The fish then moved southward, most of them likely returning to the central Pacific and some to the fishery the following year (see their figure 89). The migrations of fish in the southern group appeared more complex, and the inshore-offshore movements were not well defined owing to inadequate data in the offshore areas. Nevertheless, from the large number of skipjack tuna tagged in the Gulf of Panama in 1959 and 1961, many went north and west to Central America and many went south to Ecuador-Peru. At least one tagged fish moved from Ecuador and one from the Galapagos Islands to Peru.

Seckel (1972) proposed a drift model showing how ocean currents could contribute to the travel of skipjack tuna from the eastern North Pacific to Hawaii. From an earlier study (Seckel 1968) he noted that a pronounced salinity gradient, which implied a strong convergence, existed at the boundary of the North Pacific Central Water. Using the geostrophic and wind-driven current speeds he calculated the monthly drift displacement of 11 objects hypothetically placed between lat. 10° and 20°N along long. 120°W at monthly intervals. The results of his calculations show that objects initially locat-

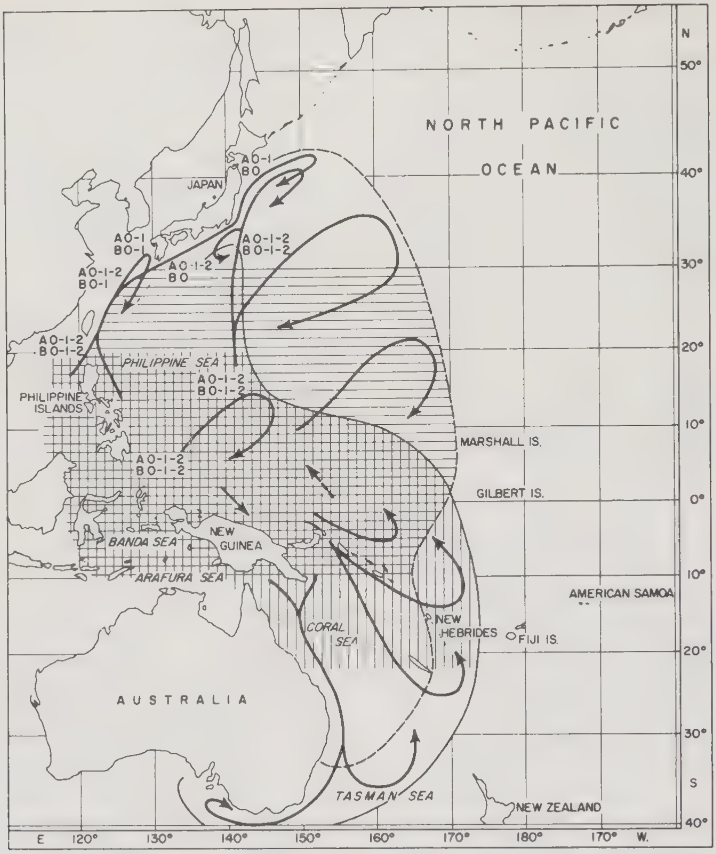

N
50°
NORTH PACIFIC
OCEAN
40°
JAPAN
AO-1
BO
AO-1
BO-1
AO-1-2
BO-1-2
AO-1-2
BO-1
AO-1-2
BO
30°
AO-1-2
BO-1-2
20°
PHILIPPINE SEA
AO-1-2
BO-1-2
PHILIPPINE ISLANDS
10°
MARSHALL IS.
AO-1-2
BO-1-2
GILBERT IS.
0°
NEW GUINEA
BANDA SEA
ARAFURA SEA
10°
AMERICAN SAMOA
CORAL SEA
NEW HEBRIDES
FIJI IS.
20°
AUSTRALIA
30°
S
TASMAN SEA
NEW ZEALAND
40°
E
120°
130°
140°
150°
160°
170°
180°
170°
W.

Figure 10.—Range and migration routes of skipjack tuna of the western subpopulation. The eastern limit of distribution is indicated by thin solid line (northern winter) and broken line (northern summer). Migration routes are shown by arrows. The numerals with A or B represent age classes of fish from summer or winter spawning, respectively. Intensive spawning grounds in the northern summer and northern winter are shown by horizontal and vertical hatching, respectively. [Reproduced from Fujino (1972).]

ed south of lat. 15°N rapidly drifted northward and all were north of lat. 15°N by the time they had crossed long. 128°W; that the objects appeared to concentrate on the northern and southern edges of their distribution and to merge west of long. 150°W in a relatively narrow band between lat. 18° and 22°N, so that the initially meridional distribution of objects along long. 120°W became oriented along the northern edge of the equatorial current west of long. 160°W after 24 mo. The minimum duration of drift of objects from long. 120° to 155°W ranged from 21 to 23 mo, which is of the same order of magnitude as the duration of freedom of four of the seven skipjack tuna tagged in the eastern Pacific and recovered in Hawaii. As a result of this model Seckel (1972) postulated that a possible, and the simplest, mode by which skipjack tuna travel from the eastern Pacific to Hawaii, is by swimming randomly and drifting with the current.

Williams' (1972) proposal included three migration models of young skipjack tuna that enter the eastern Pacific fishery areas on the basis of oceanographic conditions and events in the central-east Pacific. In the first model (active migration), he proposed that skipjack tuna larvae and early juveniles in the equatorial area west of long. 130°W are located principally in the westward flowing North Equatorial Current (NEC) and South Equatorial Current (SEC); that the juveniles orient themselves eastward and migrate in that direction along the zonal "productivity" bands at the northern and southern boundaries of the North Equatorial Countercurrent (NECC) and enter the offshore areas of the southern fishery; that the cessation of the surface NECC east of long. 120°W from January through May disrupts the orientation and movement of skipjack tuna juveniles through significant changes in the position and continuity of the "productivity" bands, at which time the skipjack tuna are reoriented to the northeast and enter the northern fishery following a "food bridge" (i.e., pelagic stages of the red crab, *Pleuroncodes planipes*), linking that area with the Revilla Gigedo Islands and

Baja California. In the second model (passive migration), he proposed that larval and juvenile skipjack tuna are passively carried eastward in equatorial countercurrent(s), but he admits to problems in recruitment of fish to the northern fishery from the terminus of the countercurrent. In the third model (gyral migration), developed after personal communication with me when this report was in the early stages of preparation, he proposed that fish in the northeastern Pacific fishery move around a zonally narrow counterclockwise equatorial gyre consisting of the NECC and the NEC. In this model, he considered that skipjack tuna spawn in northern spring and summer in equatorial waters west of long. 130°W; the larvae and early juveniles are carried eastward in the NECC to the area south of the Revilla Gigedo Islands where the juveniles, now of near recruitment size, actively migrate out of the gyre into the Revilla Gigedo waters and subsequently into the feeding grounds off Baja California; and with the advance of cold water in late fall the skipjack tuna leave the area via the California Current Extension (CCE) to return to the equatorial spawning grounds. He also proposed that skipjack tuna forming the southern group spawn in the southern spring and summer in the central equatorial Pacific; that the larvae and juveniles north of the equator enter the NECC and are carried eastward were, on reaching the terminus of the NECC, the juveniles actively migrate into the feeding areas off Central and South America, leaving there via the SEC; and that larvae and juveniles south of the equator are carried eastward in the South Equatorial Countercurrent (SECC) and return to the central Pacific as adults in the SEC.

Kasahara (1968) cited the hypothetical movements of skipjack tuna on a Pacific-wide basis developed by Naganuma (Unpubl. manuscr., see footnote 2). The movements are based on catch as well as monthly variations in length frequencies of skipjack tuna taken in the Japanese longline fishery in 1965 (Fig. 11).

Of the seven hypotheses above, only that by Naganuma (in Kasahara 1968) shows the migration of skipjack tuna on an oceanwide basis; others deal with more restricted areas in the Pacific which contain today's major fisheries or discuss movement in general without indicating actual migratory routes. For the most part, however, the routes proposed by Nagnuma in the western and central North Pacific and eastern South Pacific are incomplete, due to his reliance upon only one year's data, and his proposed route in the central South Pacific could be opposite to the direction indicated (see following discussion).

Movement of Skipjack Tuna Inferred from Present Study

To detect movement, the positions of high (>4× mean) CPUE were noted and connected by arrows in quarterly sequence beginning with the earliest year (Fig. 12), on the assumption that the quarterly changes in the high-CPUE postions reflected actual movement of fish. In some areas lacking in high-CPUE cells, above-average (2 × -4 × mean) CPUEs were followed to complete the movement pattern. In the figure, areas of above-average CPUE in the first quarter of two or more years were shaded to show that high-CPUE cells are not

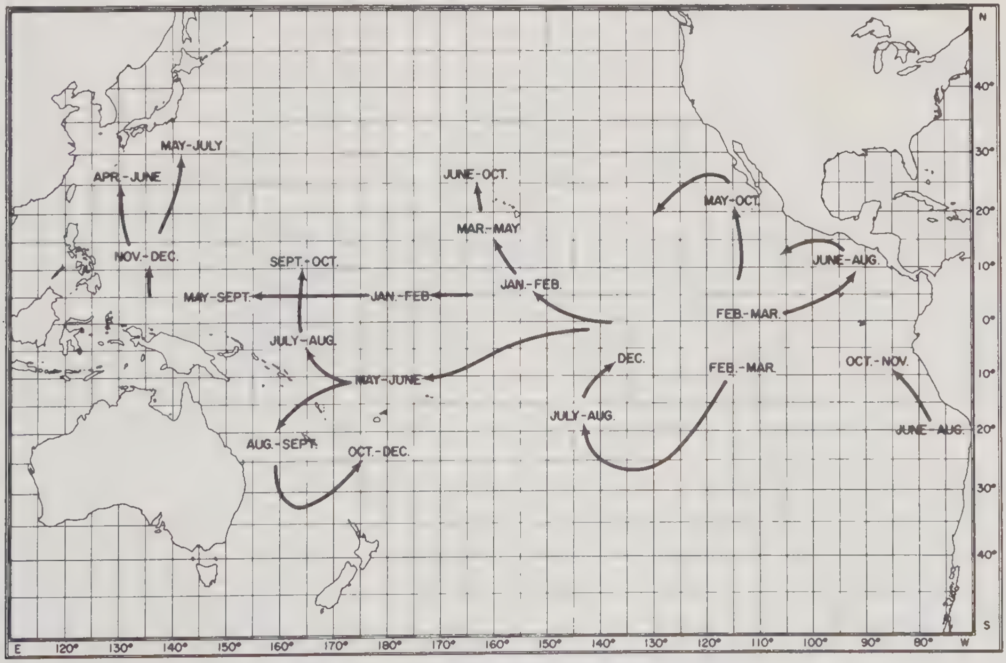


Figure 11.—Migration routes of skipjack tuna proposed by Naganuma (unpublished manuscript, see text footnote 2) based on tuna longline data. [Reproduced from Kasahara (1968).]

always discrete or isolated units. Other quarters also show large areas of above-average CPUEs within which high-CPUE cells are grouped.

Given the set of numerals denoting high-CPUE positions by quarters, one could show arrows pointing in directions other than those shown, but such a change in direction would be contrary to the seasonal movements of the surface fishery (and also tag return data) in areas where this is known. In Japanese waters, for example, the skipjack tuna are known to enter the fishery from the south and southwest, continue northeastward along the southern coast of Japan and then move offshore in an easterly direction with the progression of the seasons from spring through late fall (Kimura 1949; Kasahara 1971; Kasahara et al. 1971); in the eastern Pacific, the skipjack tuna are known to enter the northern fishery off central Mexico in about the second quarter, move northward in succeeding quarters, and presumably move offshore and back to the central equatorial areas in late fall (Fink and Bayliff 1970; Williams 1972). Although the direction of seasonal movement of fish in the eastern Pacific is opposite to that in the western Pacific, certain factors that could determine the movement pattern are common to both areas. First, the east-west component of the movement of high-CPUE cells generally follows that of the prevailing surface currents. Second, there is a poleward shifting of the high-CPUE cells corresponding to a similar shifting of the warm isotherms during late spring to fall, and an equatorward shifting during winter and early spring. The net effect of surface current flow and poleward shifting of skipjack tuna in response to seasonal warming of the water thus would result in roughly circular paths.

On the basis of these observations, roughly circular paths were drawn (Fig. 12) in the direction of the prevailing currents (Fig. 13) to indicate the probable movement of skipjack tuna in all regions of the Pacific. Thus, in the southern hemisphere, where the major ocean currents flow counterclockwise around the South Pacific Central Water mass, the movement of skipjack tuna are shown in counterclockwise paths. In the northern hemisphere, where the major currents flow clockwise, the paths of skipjack tuna movement are also clockwise, except in the eastern Pacific, where current flow around the North Pacific Equatorial Water mass is counterclockwise. The correspondence of skipjack tuna movement to current flow is believed to be more than incidental, as hypothesized for albacore in the waters off Japan and yellowfin tuna off eastern Australia by Nakamura (1969).

The several paths depicted in the figure suggest that skipjack tuna in the Pacific Ocean may be composed of different groups (not necessarily separate subpopulations), possibly seven in the northern and seven in the southern hemispheres. For ease of discussion, these will be referred to as environmentally defined "groups" of skipjack tuna. A schematic diagram of the group movements is presented in Figure 14.

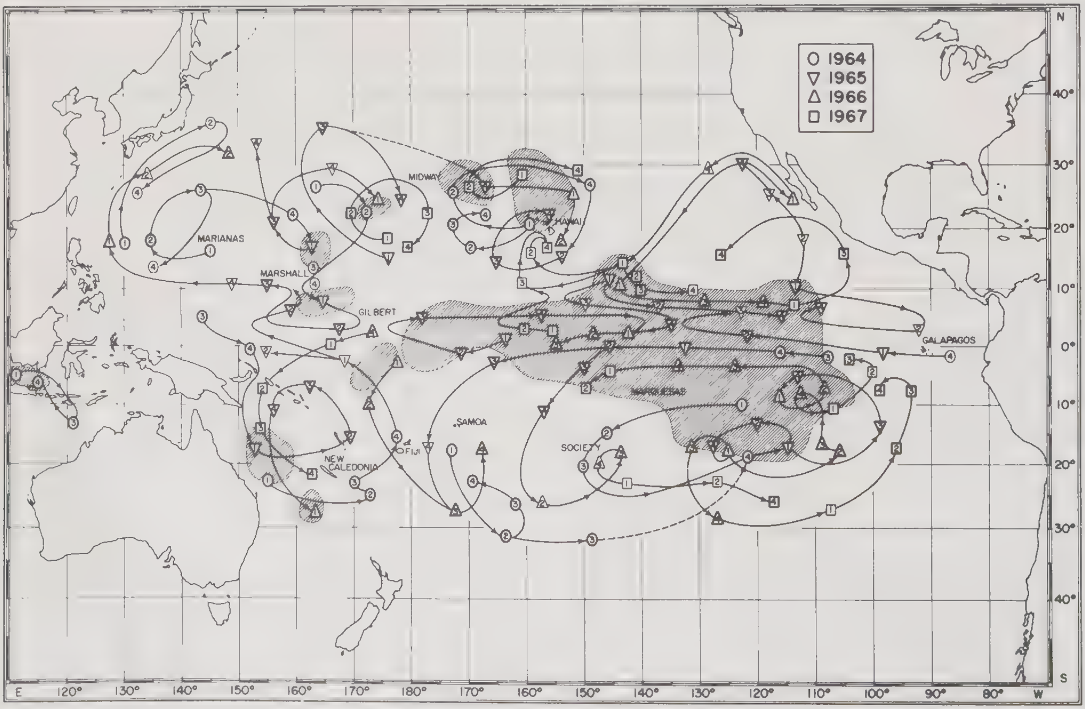


Figure 12.—Quarterly changes in position of high-CPUE areas in the Japanese tuna longline fishery, 1964-67. The shaded areas denote above-average CPUE areas in the first quarter of 2 or more years.

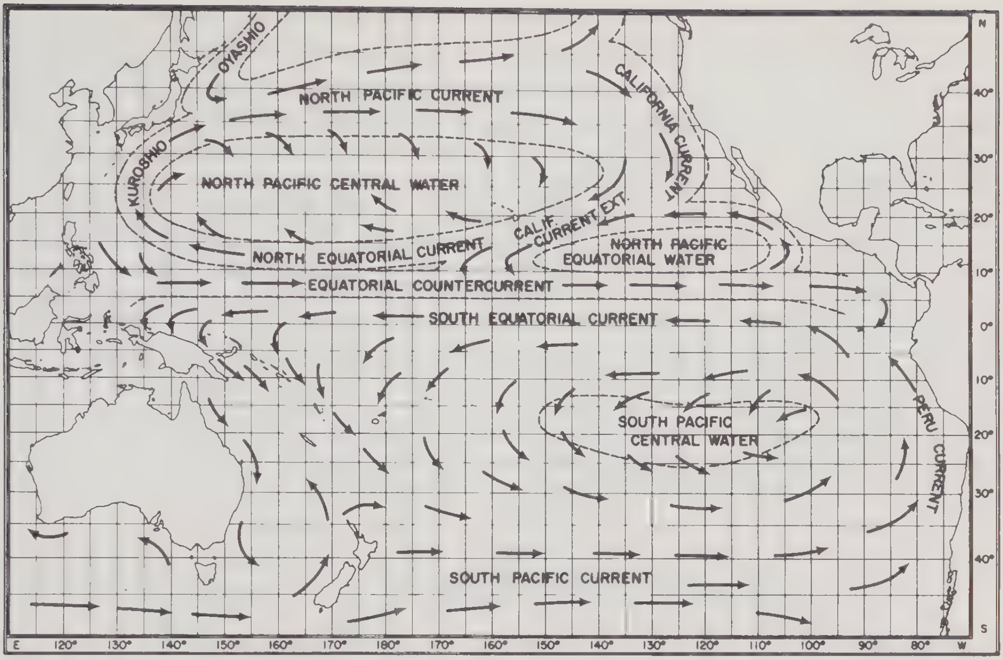

OYASHIO
NORTH PACIFIC CURRENT
CALIFORNIA CURRENT
KUROSHIO
NORTH PACIFIC CENTRAL WATER
CALIF. CURRENT EXT.
NORTH PACIFIC EQUATORIAL WATER
NORTH EQUATORIAL CURRENT
EQUATORIAL COUNTERCURRENT
SOUTH EQUATORIAL CURRENT
SOUTH PACIFIC CENTRAL WATER
PERU CURRENT
SOUTH PACIFIC CURRENT
N
40°
30°
20°
10°
0°
10°
20°
30°
40°
S
E
120°
130°
140°
150°
160°
170°
180°
170°
160°
150°
140°
130°
120°
110°
100°
90°
80°
W

Figure 13.—Major circulation features of the Pacific Ocean. [Based on Sverdrup, Johnson, and Fleming (1946) and [U.S.] Bureau of Commercial Fisheries (1963).]

Western Pacific.—At least three groups, perhaps more, may be present in the northwestern Pacific (north of the equator and west of long. 180°). The westernmost groups, originating off the Philippine (NW1) and the Mariana-Marshall islands (NW2) in the first quarter, apparently move northward through Japanese waters in the second and third quarters and return south in the fourth quarter (Fig. 14). The third group (NW3), originating east of the Marshall Islands, moves northwestward into the Japanese offshore waters in the second and third quarters and returns southeastward in the fourth quarter to the area southwest of Midway Island. Part of this group could move farther downstream of the Kuroshio to the area east of Midway Island.

In the area south of the equator and west of long. 180°, two major movement patterns are suggested. The group (SW1) off northeastern Australia moves southward along the continent in the first quarter, then eastward south of New Caledonia in the second and third quarters, and returns northward either through or slightly west of the Fiji Islands in the fourth quarter. At or near the equator, part of this group may continue northward and subsequently mix with the western groups in the northern hemisphere, while the other part continues westward, returning south in the following season. The second major movement pattern is seen in the group (SW2) originating near the Gilbert Islands in the fourth quarter. This group follows a path southwestward into waters east of New Guinea in the second quarter of the following year and into waters off New Caledonia in the fourth quarter.

Eastern Pacific.—The group (NE1) in the eastern Pacific north of the equator (east of long. 130°W) likely originates in equatorial waters, mainly in the NEC. Its movement is toward the Mexican coast in the second quarter, north along the coast in the third quarter, and subsequently back to equatorial waters in the fourth quarter (Fig. 14). Part of this group (NE2) branches eastward toward Cocos Island (perhaps fish that form part of the southern fishery) and returns westward in the SEC. The proposed movements of these fish generally agree with the movements of fish in the surface fishery as determined from tagging results by Fink and Bayliff (1970), and are similar to those proposed by Rothschild (1965) and Williams (1972) for this area. Although Fink and Bayliff (1970) do not show any tagging effort in the Clipperton Island area, a recovery at Cocos Island of a skipjack tuna tagged in the Revilla Gigedo Islands (Inter-American Tropical Tuna Commission 1966) suggests that the route of group NE2 (Fig. 14) is not improbable.

In the area south of the equator (east of long. 130°W), the movement suggested by the longline catches is generally southward in the first and second quarters and northward in the third and fourth quarters. The area seems to contain several groups (SE1, 2, 3), which revolve about an area midway between the Society Islands and the South American coast. The movement patterns of these groups correspond with the circulation gyre formed by the South Pacific, Peru, and South Equatorial Currents. The data suggest that these groups may require more than a year to complete the circuit.

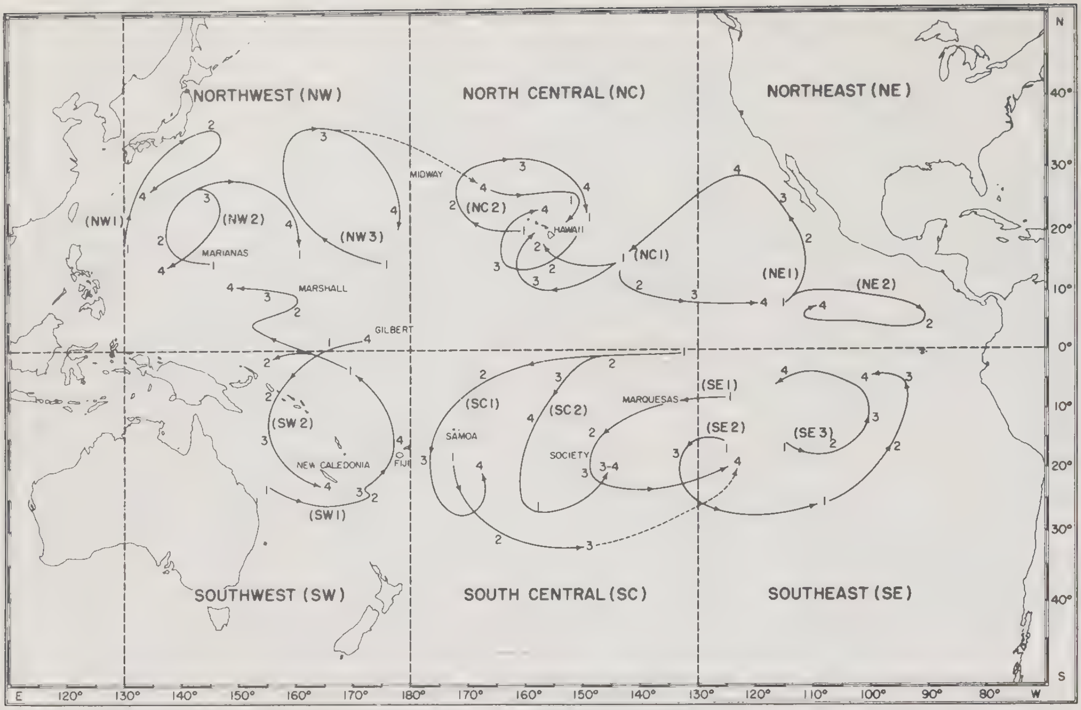


Figure 14.—Assumed movement of the various stocks of skipjack tuna in the Pacific Ocean. The numerals along the migratory routes represent quarters and locations of high-CPUE cells of skipjack tuna taken by the Japanese tuna longline fishery, 1964-67. Stock designations are shown in parentheses.

Central Pacific.—In the central (long. 130°W to 180°) North Pacific, particularly the area between Hawaii and Midway, two or possibly more groups may be present. One group (NC1), originating in the NEC to the southeast of Hawaii, could move directly into the Hawaiian fishery in the second quarter. A portion of this group could move farther downstream in the CCE taking a longer route before entering the Hawaiian fishery in the third or fourth quarter. At least part of this group consists of fish that have migrated from the eastern Pacific northern fishery area. A second group (NC2), originating west of Hawaii, could move into the Midway Islands area in the second quarter, then continue to an area northeast of Hawaii in the third or fourth quarter, winter there, and move into Hawaiian waters in the second or third quarter of the following year. This could be a purely local group, from offspring originating in Hawaiian waters. Fish from a third group of the northwestern Pacific (NW3) could move into the Midway Islands area via the Kuroshio extension and arrive in the Hawaiian fishery 1 or 2 yr later.

In the central South Pacific at least two major routes, possibly representing the same group of skipjack tuna, are indicated. The first group (SC1), originating at the equator near long. 130°W, moves westward in the first and second quarters, southward in the third quarter, passing near the Fiji Islands, and northward in the fourth quarter, into the Samoa area. The second group (SC2), having the same origin as the first, moves at a slower pace, turning southward in the second quarter and passing between Samoa and the Society Islands between the fourth quarter and first quarter of the following year. It turns northeastward in the second quarter and arrives in the Society Islands area in the third or fourth quarter. Both groups could conceivably swing southward and eastward during the following year and end up in the southeastern sector of the Pacific 15° to 20° latitude south of the equator.

DISCUSSION

The movement of skipjack tuna interpreted from longline catches generally agrees with that hypothesized by Fujino (1972) for the western Pacific and by Rothschild (1965) and Williams (1972) for the eastern Pacific. In the western Pacific, movement patterns not only bear out the demarcation of the two subpopulations reported by Fujino (1970a), but show that the demarcation line and area of intermingling between the two subpopulations agree quite well with those described for the surface fishery. The movement patterns of the groups of skipjack tuna in the western Pacific subpopulation (NW1 and NW2) are of particular interest since they permit the qualification of Kawasaki's (1965) suggestion that there is an exchange of skipjack tuna populations between Japanese and Hawaiian waters. The possibility of such an exchange is indicated in Figure 14 (dashed line from Japanese offshore waters to area east of Midway).

Continued movement eastward in subsequent quarters could find these fish in Hawaiian waters. Any such move, however, can be made only by fish of the central-eastern Pacific subpopulation (NW3), since Fujino (Kitasato University, Iwate Prefecture 022-1, Japan, pers. commn.) has indicated that no fish of the western Pacific subpopulation have been sampled in the Hawaiian fishery.

The migration paths of deep-swimming skipjack tuna of the western subpopulation in the southern hemisphere (SW1 and SW2) closely resemble those of the surface fishery postulated by Fujino (1972), even to the possibility of the southern groups moving across the equatorial current system, which could result in the mixing of fish of both hemispheres. The area west of Fiji seems to be the dividing line between the western and central-eastern skipjack tuna subpopulations in the South Pacific.

In the eastern Pacific, the migration of skipjack tuna (NE1) into the northern fishery, based on longline catches, is similar to that of the surface fishery as postulated by Rothschild (1965) and Williams (1972). Even the latter's "food bridge" theory linking the area of the NECC east of long. 120°W to the Revilla Gigedo Islands and Baja California is suggested in the progression of longline catches (indicated by +'s) from the second through the third quarters (Fig. 4). Williams also hypothesized the possibility of a surface SECC as an additional mechanism of eastward transport of juvenile skipjack tuna into the eastern Pacific southern fishery. Although a surface SECC has been identified as extending from the Solomon Islands to the coast of South America along lat. 10°S (Reid 1961), its occurrence at the surface in the area east of long. 120°-140°W has not been clearly defined. Wyrtki (1965) suggested that the SECC exists there only in subsurface layers, whereas Tsuchiya (1970, 1972) doubted the existence of zonal continuity all the way across the ocean. Recently, Tsuchiya (1974) recognized an eastward surface current (average speed of 7 cm/s) along lat. 10°S between long. 112° and 90°W in the southern summer. It should be noted, however, that the current may be too weak and too short to play a major role in supplying recruits into the eastern Pacific southern fishery.

Table 4.—Skipjack tuna tagged in the eastern Pacific and recaptured in the central Pacific (Seckel 1972).

Tagged fish	Release		Recapture		Months free
	Date	Area	Date	Area	
A	5 Sept. 1960	Baja California	12 June 1962	Hawaii	21
B	17 Apr. 1960	Revilla Gigedo Is.	22 Aug. 1962	Hawaii	28
C	22 Sept. 1961	Baja California	5 Apr. 1963	Christmas Is.	18
D	5 June 1965	Revilla Gigedo Is	27 June 1967	Hawaii	24
E	6 Nov. 1969	Clipperton Is.	21 July 1970	Hawaii	9
F	6 Nov. 1969	Clipperton Is	8 Aug. 1970	Hawaii	10
G	26 Oct. 1969	Lat. 4°11'N, long. 119°02'W	14 July 1971	Hawaii	21

The longline data discussed herein not only demonstrate a possible avenue of southern hemisphere skipjack tuna migration into the southern fishery, but show this to be possible without the presence of a SECC. According to the longline data, adult skipjack tuna are present as far south as lat. 20°S and as far east as long. 90°-95°W in the second and third quarters. The offspring of these fish could easily enter the wake system of the Galapoagos islands by simply moving along with the current (Fig. 13). Once there the move into the South American coastal waters can be made actively, as demonstrated by tagging results (Fink and Bayliff 1970, fig. 90).

The return route of skipjack tuna from the eastern Pacific northern fishery to the equatorial central Pacific spawning grounds is seen more clearly in the longline data than in the schematic presentation by Williams (1972). It seems that the westward movement of fish extends farther west, past long. 140°W, and this is corroborated by the recovery near Christmas Island and Hawaii of seven fish tagged in the eastern Pacific fishery (Table 4). These recaptures indicate that at least part of the fish returning to equatorial waters from the eastern Pacific migrate to Hawaii and the Line Islands, while the remainder could return eastward in the NECC.

Much of the westward migration of skipjack tuna from the eastern Pacific to Hawaii probably occurs in the area covered by Seckel's (1972) drift hypothesis, i.e., lat. 10°-20°N, long. 120°-160°W. Seckel gave 21-23 mo as the average minimum duration of westward drift through this area, and cited the possibility of even shorter drift periods if the skipjack tuna were caught in cells of high westerly flow of more than 25 cm/s (Seckel, 1972, fig. 17). Such a flow could take the skipjack tuna well over 3,900 km (2,100 nautical miles) in 6 mo. Both the average minimum drift period and the accelerated drift period are reflected in the recoveries in Hawaii of fish tagged in the eastern Pacific. Of six such recoveries, four were of 21-28-mo duration and two were of 9-mo duration (Table 4). The duration of skipjack tuna migration from northern Baja California to Hawaii suggested by the tuna longline data is 6 mo, similar to that attainable by fish in the cells of high westerly flow.

That the movement of the skipjack tuna in the above area involves more than just being transported by the surface currents is evident from the seasonal shifting of the northern boundary of distribution of the adults. The boundary shifts northward in the third and fourth quarters and southward in the first and second quarters (Fig. 8). More likely than not, the skipjack tuna in this region move southward actively in response to the southward advance of cool water from late fall to early spring, the fish seeking an environment more in accord with spawning than with feeding requirement (Blackburn and Williams 1975). Support for this view is seen in the northern limit of larval skipjack tuna occurrence within this region. The distribution of skipjack tuna larvae terminates sharply at lat. 10°-12°N between long 110° and 150°W (Matsumoto 1966).

Utilizing information gained from tagging by Fink and Bayliff (1970), the drift model by Seckel (1972), and the longline catch data, one could postulate the routes followed by the tagged fish from the eastern to the central Pacific (Fig. 15). Fish A, tagged off Baja California in September 1960 and recaptured in Hawaii in June 1962, had been at liberty for 21 mo. Fish B, tagged off the Revilla Gigedo Islands in April 1960 and recaptured in Hawaii in August 1962, had been at liberty for 28 mo. Considering that fish B had been tagged 5 mo earlier than fish A, that the general movement of fish in the eastern Pacific is northward in the third quarter, and that both fish had been recaptured in the same season (only 2 mo apart) in Hawaii, it is not unreasonable to assume that fish B had been tagged from the same group of fish (either school or schools) as fish A and that both fish, having left the eastern Pacific fishery in the fourth quarter, had a) entered the Hawaiian fishery in the following spring, remaining in the area a full season before being recaptured (routes A1, B1), or b) followed the longer routes A2, A3, B2, or B3.

Fish C, tagged off Baja California in September 1961 and recaptured east of Christmas Island in April 1963, was at liberty for 18 mo. The elasped time from release to recovery and the movement across the NECC suggest that the fish followed route C1 or C2, or some route between the two. The recovery of this fish in the SEC shows that the movement involved active migration as well as drifting with the current.

Fish D, tagged off Revilla Gigedo Islands in June 1965 and recaptured in Hawaii in June 1967, had been at liberty for 24 mo. This fish probably followed a path similar to that taken by fish B.

Fish E and F, tagged in November 1969 off Clipperton Island and recovered in Hawaii 9 and 10 mo later, respectively, lighely followed a shorter, more direct route, migrating nearly due west into the Hawaiian area and being caught soon after arrival. Such a movement is possible simply by drifting with the current, as indicated by Seckel (1972), with a minimum of active migration by the fish. Current trajectories drawn from monthly sea surface current charts also indicate a current path similar to that shown in Figure 15, with a time requirement of 11 mo between the two islands (Barkley, Southwest Fisheries Center, National Marine Fisheries Service, NOAA, pers. commn.).

Fish G was tagged by the Honolulu Laboratory at lat. 4°11′N, long. 119°02′W on 26 October 1969 and recaptured in Hawaii 21 mo later on 14 July 1971. Based on the length of time at liberty, this fish likely had passed through the eastern Pacific fishery during the first year and had entered the Hawaiian fishery in the second or third quarter of the following year. A path that coincides with the assumed paths of fishes A, B, and D, and with the quarterly movement of high-CPUE cells of the longline fishery can be projected without exaggeration. The importance of this recovery, as well as the one east of Christmas Island, is that it showed the ability of the skipjack tuna to migrate across the NECC at a time when the current was well developed.

An alternate route that these fish could have taken in moving from the eastern Pacific to Hawaii is directly across the California Current (Fig. 14, route A4, B4, C3, D4, and G2). It seems unlikely that they did this, however, because 1) if this was the normal migratory route, the longline catches of skipjack tuna there should have been much higher than those recorded, yet the CPUE in each 5° area was not only low, but inconsistent from year to year; and 2) fish C would have had to move counter to the seasonal trend between Hawaii and the equatorial region without dallying in Hawaiian waters. It would seem more likely that once fish C had entered the Hawaiian fishery it would have stayed there for the remainder of the season and perhaps into the next as well.

In the central Pacific, the movements of skipjack tuna derived from longline catch data largely represent new information. In the area north of the equator, between Midway and Hawaii, the movement patterns indicate entry of fish into the Hawaiian fishery from 1) the eastern Pacific (corroborated by tag recoveries), 2) equatorial waters to the south, and possibly 3) the Japanese offshore fishery. Additionally, there could be a strictly local stock within the area. Captures of larval skipjack tuna (Matsumoto 1958) around Hawaii indicate that the species spawns there from spring through early fall. Some of the larvae remain in the vicinity of the islands and develop through the early juvenile stages, but many are undoubtedly carried downstream in the prevailing westerly current. Some of these probably get caught in the North Pacific gyre and return the following year or the year after as either 1- or 2-yr-old fish. An indication of the presence of fish from these several sources in the Hawaiian fishery was hinted at by Rothschild (1965). From length-frequency distributions of fish taken by the fishery, he recognized typical modal lengths of 35, 50, and 70 cm in winter and 45 and 75 cm in summer. Because the positions of the modes did not necessarily increase with time, Rothschild reasoned that the data suggested passage of successive groups of skipjack tuna through the fishery and that this passage was not uniform with respect to time.

In the South Pacific, at least two types of migratory routes are indicated: a short route that takes fish from an area east of the Marquesas through the Society Islands and back to an area southeast of the Marquesas Islands within 1 yr, and a longer route that takes fish from the equator northeast of the Marquesas to as far west as the Samoa-Fiji area and back east to an area southeast of the Marquesas Islands in 2, or possibly 3, yr.

The image one gets from these projected routes of migration of the central-eastern Pacific subpopulation is that the skipjack tuna or their progeny can wend their way in due time from the eastern Pacific to the boundary of the western Pacific subpopulation in both hemispheres.

How well this model of stock identification and migration reflects the actual conditions in the Pacific Ocean can be tested by the more positive means of tag

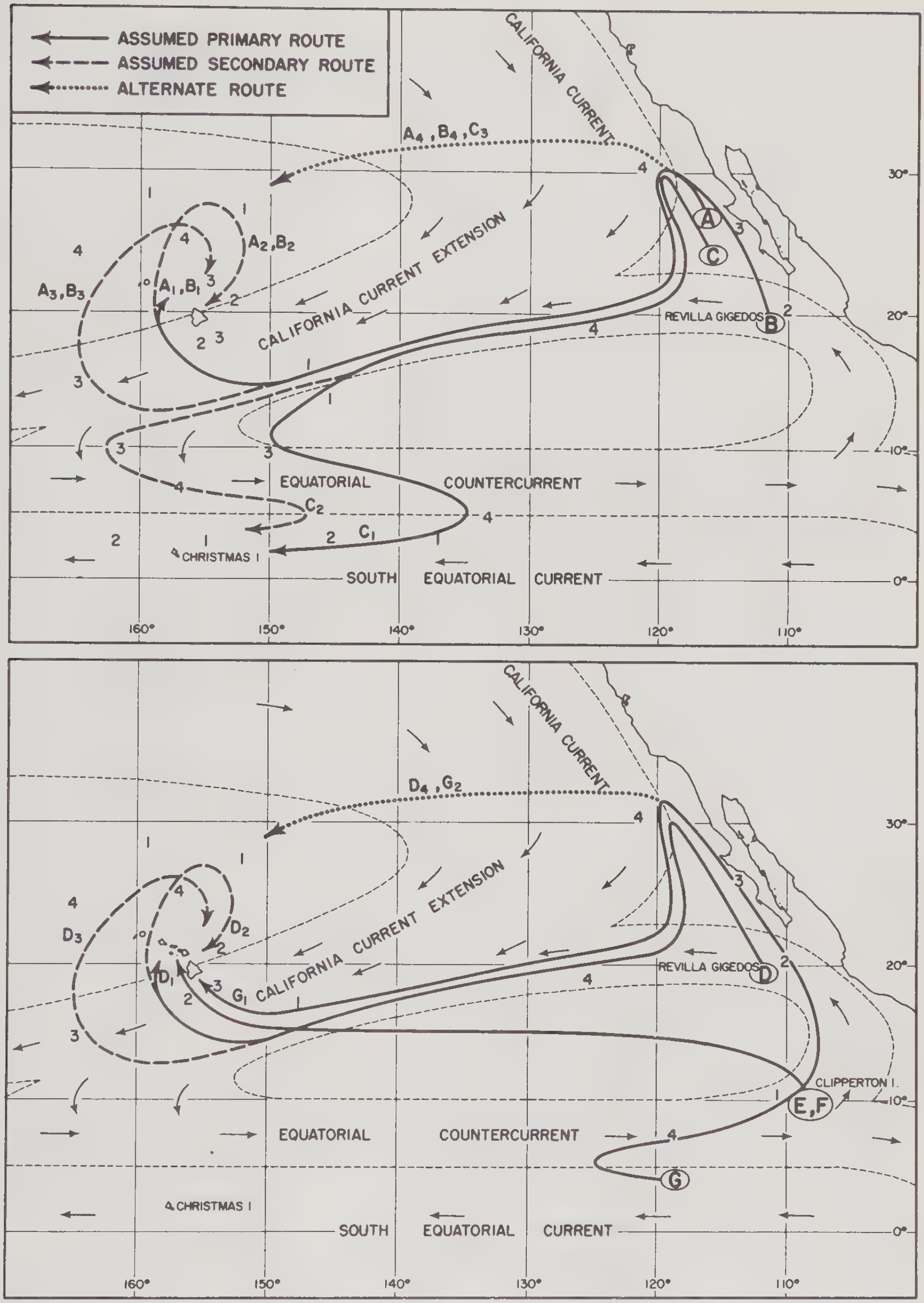

ASSUMED PRIMARY ROUTE
ASSUMED SECONDARY ROUTE
ALTERNATE ROUTE
CALIFORNIA CURRENT
A4 ,B4 ,C3
A2,B2
A3,B3
A1,B1
CALIFORNIA CURRENT EXTENSION
REVILLA GIGEDOS
A
B
C
C2
C1
EQUATORIAL
COUNTERCURRENT
CHRISTMAS I
SOUTH
EQUATORIAL
CURRENT
D4 ,G2
D2
D3
D1
G1
D
E,F
G
CLIPPERTON I.
30°
20°
10°
0°
160°
150°
140°
130°
120°
110°

Figure 15.—Assumed routes followed by tagged skipjack tuna from the eastern to the central Pacific. The letters represent tagged fish and the numerals along the routes represent quarters of high catch rates of skipjack tuna taken by the Japanese tuna longline fishery, 1964-67.

returns. Unfortunately tagging of skipjack tuna in the past has not been as widespread nor as consistent and intensive as desirable. In the few areas where tagging has been done on a moderate scale, i.e., in the eastern and northwestern Pacific, the few tag recoveries have aided in developing parts of this model. Much more tagging effort is needed in these and other areas, however, if we are to gain a better knowledge of skipjack tuna migration in the Pacific Ocean. A model such as this could be the basis upon which a Pacific-wide tagging experiment could be developed.

SUMMARY

1. Skipjack tuna are taken mainly in surface fisheries that are restricted to coastal waters. Consequently, our knowledge about the distribution of these fish is equally limited. To get a better idea of the distribution, abundance, and movement of skipjack tuna in noncoastal waters, data of the Japanese tuna longline fishery from 1964 through 1967 were analyzed by determining the catch-per-unit effort (CPUE) for each 5° area of latitude and longitude by quarters for each of the years. Contours were drawn of the CPUE values to determine high-CPUE areas or cells and their movements from quarter to quarter.

2. The concentrations of zero catches at the northern and southern boundaries of the fishery indicated that fishing had occurred throughout the distributional range of the skipjack tuna.

3. Large skipjack tuna were found to be concentrated a) east central equatorial Pacific; b) eastern Pacific south of lat. 10°S; c) central North Pacific, north and northwest of Hawaii, and in Hawaiian waters; d) western North Pacific, south and east of Japan; and e) western South Pacific, northeast and east of Australia. The distribution of CPUE was characterized by a) the absence of uniformity in the northward and southward shifts of the northern and southern boundaries and along the boundaries across the Pacific; b) the persistence of a very large area of better-than-average CPUE in the east central equatorial Pacific (between long. 130°W and 180°, and between lat. 10°N and 15°S); and c) the disparity between high catch areas of the longline and the surface fisheries.

4. The relative abundance of adult skipjack tuna was suggested in the relative abundance of larvae in tropical and subtropical waters. The abundance was low in the eastern Pacific east of long. 120°W, high in the central Pacific between long. 120°W and 160°E, and low in the western Pacific between long. 120° and 160°E. A similar trend also was noted in the longline catches of skipjack tuna.

5. The apparent movement of groups of skipjack tuna in the Pacific appeared to coincide with the circulation of the major ocean currents. The movement was counterclockwise in the southern hemisphere and clockwise in the northern hemisphere, except in the eastern Pacific where the movement appeared counterclockwise, corresponding with the flow in the north equatorial water mass.

The movement patterns of high CPUE suggested the occurrence of a number of groups of skipjack tuna, possibly 14 or more, in the Pacific. The movement of the four westernmost groups, two each in the northern and southern hemispheres, generally agreed with those of the two western Pacific subpopulations of skipjack tuna proposed by Fujino (1972). Each group of the central-eastern Pacific subpopulation of (Fujino 1970a) seemed to follow its own seasonal migratory pattern that permitted movement of adults or their progeny from one area to the next, e.g., 1) skipjack tuna in the eastern Pacific northern fishery apparently originated in and returned to central equatorial waters, with part of the group moving into Hawaiian waters in subsequent seasons and part to the Line Islands area south of the equatorial countercurrent; 2) skipjack tuna in the Midway-Hawaii area were apparently composed of groups from the eastern and equatorial Pacific, from waters farther west between Midway and Wake Island, and possibly from the Marshall Islands and Japanese offshore surface fishery; and 3) part of the skipjack tuna in the eastern Pacific southern fishery apparently originated in the South Pacific to the east and south of the Marquesas Islands.

6. The migration of skipjack tuna from the eastern Pacific to Hawaii had been established by recoveries there of five fish tagged in the eastern North Pacific and one fish tagged in the eastern Pacific near the southern edge of the Equatorial Countercurrent (lat. 4°11′N, long. 119°W). The migratory routes of these fish as well as a seventh fish tagged in the eastern Pacific northern fishery and recovered near Christmas Island were postulated. The five fish recovered in Hawaii presumably departed the eastern Pacific fishery area in late fall and arrived in Hawaiian waters via the California Current Extension in the following spring or summer. The fish tagged near the southern edge of the Equatorial Countercurrent moved through the eastern Pacific fishery and then to Hawaiian waters via the California Current Extension where it was recaptured soon upon arrival. The fish tagged off Baja California and recaptured east of Christmas Island left the tagging area in late fall, arrived in equatorial waters via the California Current Extension and remained there a full year before being recaptured. The latter two recoveries were especially noteworthy since they demonstrated that skipjack tuna can move across the Equatorial Countercurrent.

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Acute Toxicity of Benzene, a Component of Crude Oil, to Juvenile Striped Bass (*Morone Saxatilis*)

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MEYERHOFF, R. D. 1975. Acute toxicity of benzene, a component of crude oil, to juvenile striped bass (*Morone saxatilis*). J. Fish. Res. Board Can. 32: 1864–1866.

As the biological effects of the volatile aromatic compounds in crude oil are not well documented, a systematic examination of these compounds was initiated at the National Marine Fisheries Service at Tiburon. One of the major constituents of these aromatic compounds is benzene. The acute toxicity of benzene to 1.5 ± 0.5-g juvenile striped bass (*Morone saxatilis*) was studied in a continuous flow laboratory bioassay system. At 17.4 C and 29 ppt salinity, the lethal threshold concentration and the 96-h LC50 for benzene were 10.9 μl/liter. The 95% confidence interval was 10.9 ± 0.2 μl/liter and the probit line slope, "S," was 1.1. Possible toxic mechanisms are discussed.

MEYERHOFF, R. D. 1975. Acute toxicity of benzene, a component of crude oil, to juvenile striped bass (*Morone saxatilis*). J. Fish. Res. Board Can. 32: 1864–1866.

Le peu de documentation sur les effets biologiques des composés aromatiques volatiles de l'huile brute nous a incité à entreprendre un examen systématique de ces composés au National Marine Fisheries Service, à Tiburon. Un des principaux constituants de ces composés aromatiques est le benzène. Nous avons étudié la toxicité aiguë du benzène sur de jeunes bars rayés (*Morone saxatilis*) de 1.5 ± 0.5 g dans un appareil d'analyse biologique à flot continu en laboratoire. A une température de 17.4 C et à une salinité de 29‰, la concentration de seuil létal et la CL50 après 96 h du benzène sont de 10.9 μl/litre. L'intervalle de confiance à 95% est de 10.9 ± 0.2 μl/litre, et la pente de la ligne des probits, « S », est de 1.1. Nous examinons les mécanismes toxiques possibles.

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INFORMATION concerning the potential effects of crude oil on aquatic organisms is of critical interest due to the increased incidence of oil pollution. However, in studies using crude oil as a toxicant, the data are difficult to analyze. Between batches of crude oil, any component may vary in quantity and, therefore, crude oil toxicity may vary. For this reason investigations are directed toward testing the biological effects of crude oil components. There is extensive documentation of the effects of the tar components on aquatic life (Bargmann 1971), but few reports dealing with the effects of the water soluble aromatic compounds. Therefore, a program was initiated at the National Marine Fisheries Service at Tiburon to systematically measure the effects of volatile aromatic compounds on aquatic species.

As a part of this program, the acute toxicity of benzene to juvenile striped bass (*Morone saxatilis*) was studied in a continuous flow laboratory bioassay. Benzene is an important aromatic compound because it naturally occurs in large amounts, at least 20% of the aromatics in crude oil (Brocksen and Bailey 1973), and is soluble in water, up to 1993 μl/liter in distilled water (Benville and Korn 1974). Benzene is lipid soluble and is absorbed across fish gill membranes directly into the blood (Brocksen and Bailey 1973). Striped bass were used in this experiment because they support an important recreational fishery in the Sacramento–San Joaquin Delta and the San Francisco Bay, a water system heavily used by oil tankers delivering to major refineries. Striped bass accomplish at least part of their juvenile development in this estuarine environment (California Department Fish and Game 1969). Since the respiration rate of striped bass increases as fish weight decreases (Brocksen and Bailey 1973), juvenile fish were used to attempt to obtain a sensitive measure of benzene toxicity to the species. Two bioassays were performed. The initial bioassay revealed the concentration range to be tested in the final bioassay. This report refers to the final bioassay only.

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Materials and methods — Underyearling striped bass used in this study were obtained from the fish screen retrieval system of the Bureau of Reclamation water diversion facilities near Tracy, California. By August, the fish, fed Oregon Test Diet (Lee et al. 1967), grew to the average weight (1.5 ± 0.5 g) and length (52 ± 5 mm) that they normally would attain at this time in the estuary (California Department Fish and Game 1969). Using a random numbers table, 640 of these fish were equally distributed into sixteen 70-liter aquaria and were allowed to acclimate for 1 wk. The glass aquaria used were rectangular and were approximately 30 cm wide, 60 cm long, and 40 cm high. Aquaria were covered to eliminate fish stress from laboratory disturbances. The fish were not fed during the acclimation and bioassay periods and showed a net loss of 3% of their wet weight (recorded for control fish).

Filtered and aerated water, drawn from the San Francisco Bay was used for the experiment and was monitored for physical and chemical characteristics. Temperature was recorded continuously on a Bacharach Instrument Co. Tempscribe Chart. Dissolved oxygen, pH, and salinity were measured daily with a Yellow Springs Instrument Co. Model 54 D.O. meter, a Corning Instrument Co. pH meter, and a temperature compensated A. O. Goldberg refractometer. Dissolved carbon dioxide, alkalinity, nitrate-nitrogen, and nitrite-nitrogen were determined daily with a Hach Kit.[2]

The physical and chemical parameters of water used in this bioassay closely represented those which striped bass would normally encounter when they reach the San Francisco Bay estuary. The average and range of the measured parameters were: temperature 17.4 (16.9–17.9) C, dissolved oxygen 7.7 (7.2–8.2) mg/liter, pH 7.7 (7.6–7.8), salinity 29 (28–30) ppt, dissolved carbon dioxide 6.0 (5.5–6.5) mg/liter, nitrate-nitrogen 1.5 (0.0–2.0) mg/liter, nitrite-nitrogen 0.0 (0.0) mg/liter, and alkalinity 115 (110–120) mg/liter $CaCO_3$. Banks of fluorescent lights, operated through a time switch, provided controlled illumination. Day length was adjusted weekly to correspond to the natural photoperiod.

Benzene (reagent grade) was introduced into aquaria from gas wash bottles (Benville and Korn 1974). Constant air flows were maintained through gas wash bottles filled with benzene. Volitalized benzene was bubbled through an air stone near the bottom of each aquarium. The water inlet for each aquarium was directed toward each air stone from a position 3–5 cm above. This prevented the appearance of any localized areas of high concentration. Benzene concentrations were regulated by controlling the air flows.

Initially, benzene was metered into aquaria at a high rate and stabilized test concentrations were reached within 90 min. Water in each aquarium was exchanged at a rate of 2 liters/min to achieve thorough toxicant mixing, stabilize the toxicant concentration, and prevent accumulation of nitrogenous waste. A 99% replacement of water in each aquarium was attained in 2.8 h (Sprague 1973). Benzene was removed from the effluent water by an activated charcoal filter.

Benzene concentrations were determined by a gas chromatography method suggested by P. E. Benville (personal communication 1973). Each 100-ml water sample was extracted twice with 10-ml of TF Freon (triflurotrichloroethane). A small aliquot of the 20-ml extract was injected into a gas chromatograph to yield freon and benzene peaks on a strip-chart record. The benzene peak height (PH) was then compared to that of a previously prepared benzene standard. The concentration of benzene in the water sample was computed using the following equation:

$$\text{sample } (\mu\text{l/liter}) = \frac{\text{standard } (\mu\text{l/liter}) \times \overset{\text{standard}}{\text{injected}} (\mu\text{l}) \times \text{sample PH (mm)}}{5 \times \text{extract injected } (\mu\text{l}) \times \text{standard PH (mm)}}$$

The number 5 is a factor that accounts for concentrating the benzene from 100 ml of water into 20 ml of freon. Water samples with known benzene concentrations were extracted by this method and 99% of the benzene was recovered.

The aliquot of the freon–benzene extract was injected into a 6-ft column packed with 5% Bentone-34 and 10% didecylphthalate on 80/100 mesh Chromosorb PAW. For this bioassay, the precision and accuracy of the gas chromatography were 0.1 μl/liter and, normally, ±5%.

Benzene concentrations and fish deaths were monitored at the same times (2, 4, 8, 20, 24, 32, 48, 72, and 96 h). Average test concentrations ± standard deviations were 23.1 ± 0.5 μl/liter, 20.8 ± 1.0 μl/liter, 15.6 ± 3.4 μl/liter, 14.1 ± 2.0 μl/liter, 12.9 ± 2.1 μl/liter, 11.6 ± 1.5 μl/liter, 11.2 ± 2.3 μl/liter, 10.3 ± 0.6 μl/liter, 9.6 ± 1.3 μl/liter, 7.7 ± 1.5 μl/liter, 5.9 ± 1.7 μl/liter, and 4.4 ± 0.6 μl/liter. For each test concentration, the median effective time (ET50) was estimated on log-probit paper (Sprague 1973). Median effective time confidence limits (95%) were estimated according to the method of Litchfield (1949). The 72-h LC50 and the 96-h LC50, the 95% confidence limits, and probit line slope, "S," were computed by the method of Litchfield and Wilcoxon (1949).

Results and discussion — All 160 fish used as controls were alive when the experiment was terminated. There were no fish deaths past 4320 min (72 h), so the 96-h LC50 and the 72-h LC50 (median lethal concentrations) were the same, 10.9 μl/liter. The 95% confidence interval was 10.9 ± 0.2 μl/liter and the probit line slope, "S," was 1.1. A regression was fitted to points representing the log of the average test concentration versus the log of the ET50 and is shown in Fig. 1. Since there were no fish deaths past 72 h, the asymptotic LC50 was assumed equal to the 96-h LC50, 10.9 μl/liter. A vertical asymptote was drawn in Fig. 1 connecting the calculated LC50

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[2] Use of this equipment does not constitute an endorsement of the manufacturers.

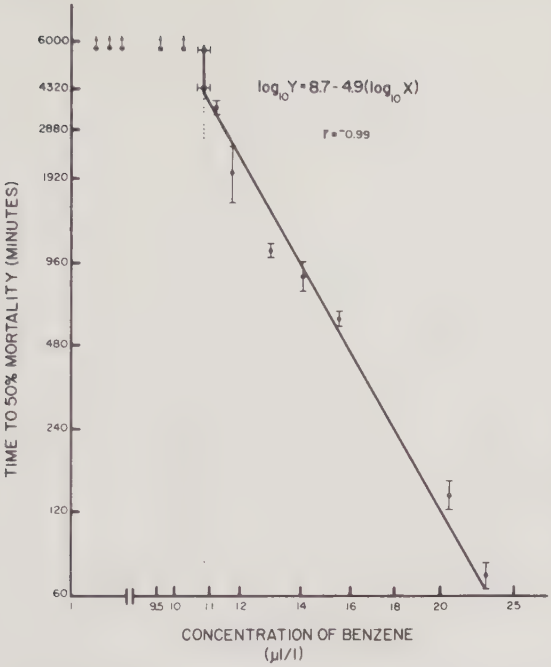

FIG. 1. Benzene toxicity curve for juvenile striped bass (*Morone saxatilis*). Confidence intervals (95%) for each point are shown.

values for 72 h and 96 h. According to a scheme listed by Sprague (1973), benzene should be considered a "toxic" substance to juvenile striped bass.

In mammals there are at least three ways benzene may cause death. Well-documented benzene-induced narcosis (Meyers 1970; Thienes and Haley 1972) is a symptom of central nervous system (CNS) depression. This CNS depression can lead to respiratory depression and collapse. Large amounts of benzene have also been found associated with erythrocytes resulting in acute anemia (Thienes and Haley 1972) and some loss of oxygen transport capacity of the blood. Benzene is known to sensitize the heart to epinephrine and any stress sends the heart into ventricular fibrillation (Thienes and Haley 1972). During ventricular fibrillation, muscle tissue of the ventricle is not contracting in a coordinated manner. Erratic contractions pump very little blood and cardiac failure rapidly follows (Guyton 1971). By all of the mentioned toxic modes of benzene, death eventually results from anoxia.

Some substantiation for these toxic modes of benzene in fish can be given. Brocksen and Bailey (1973) postulated a biochemical pathway for the detoxification of benzene. They speculated that once the detoxification capacity of the pathway was surpassed, benzene accumulated and eventually caused narcosis in the fish. This narcosis was evidenced by decreased levels of respiration in fish exposed to benzene. Also, the effects of stress on fish preconditioned to benzene can be demonstrated. When preconditioned fish are chased with a dipnet for a few seconds, they pass through a period of excitation and quickly die.

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THE EL NIÑO OF 1972-1973 IN THE EASTERN TROPICAL PACIFIC OCEAN[1]

by

Forrest R. Miller[2] and R. Michael Laurs[3]

ABSTRACT

Beginning in February 1972 the usual seasonal cooling of the surface water of the eastern Pacific Ocean in the region of the Peru Current and along the equator failed to develop. By July tropical coastal and equatorial island stations and ships crossing the equator were recording sea-surface temperatures which were 6° to 8°F (3.3°-4.4°C) above the long-term mean. The anomalies spread over most of the eastern tropical Pacific and westward into the central equatorial Pacific through September. During October surface temperatures at coastal stations along South America were returning to normal, but in November and December 1972 temperatures rose rapidly again, with a near-record temperature anomaly of 8.1°F (4.2°C) above the long-term mean recorded at Puerto Chicama, Peru (7°42′S-79°27′W). After January 1973 sea-surface temperatures began returning rapidly to normal over most of the eastern tropical Pacific, and by March 1973 the El Niño had completed its cycle.

Monthly sea-surface temperature anomalies over the eastern tropical Pacific are discussed to show the extent and magnitude of warming. Annual temperature profiles at several South American coastal and equatorial island stations are compared with temperature profiles for the 1957-1958 and 1965 El Niño years. Characteristics of the temperature anomaly profiles at Puerto Chicama during several very warm years for the 1925-1972 period are also compared. Finally, meteorological factors contributing to a relaxation of the southeast trade winds and to the decreased upwelling along the coast of South America in 1972-1973 are examined.

INTRODUCTION

Periodically large sections of the eastern tropical and subtropical Pacific Ocean undergo extensive cooling or warming in the surface layers. The large-scale anomalies, which last from several months to over a year, are thought to be manifestations of air-sea interaction processes which occur on a global scale. Anomalously warm ocean conditions, usually referred to as the El Niño phenomenon, prevailed over much of the eastern tropical Pacific during 1972-1973.

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The objectives of this paper are: (1) to describe the extent and magnitude of the warming associated with the 1972-1973 El Niño by examining anomaly patterns of monthly sea-surface temperature over the eastern tropical Pacific; (2) to compare ocean thermal conditions during the 1972-1973 El Niño with those in other El Niño periods; and (3) to examine surface meteorological factors contributing to a relaxation of the southeast trade winds and to the decreased upwelling along the coast of South America in 1972-1973.

DATA SOURCES AND METHODS

As part of a fisheries oceanography research program directed toward fisheries prediction, ocean temperature conditions for the eastern Pacific between 30°S and 60°N have been monitored since 1960 by the National Marine Fisheries Service (NMFS), Southwest Fisheries Center, La Jolla Laboratory. Most of the data used in this paper have been obtained as part of this monitoring program.

The major source of data used in preparing the charts of sea-surface temperatures (Figure 1) and anomalies from the long-term mean (Figures 2-9) are the surface marine weather reports made by ships at sea. These reports are received by scheduled synoptic transmissions from U. S. and foreign merchant, fishing, and research vessels according to procedures established by the World Meteorological Organization. About 4,000 synoptic marine weather reports, containing sea-surface temperature (SST) observations, from the eastern tropical and subtropical Pacific Ocean are processed each month at the NMFS La Jolla Laboratory. A description of how observations are received and processed is given by Johnson, Flittner and Cline (1965). Although specific program details have been changed, the present methods are essentially the same as those described in that publication. The SST data for each month are averaged by 1-degree quadrangles and plotted by computer, and isotherm charts are produced by manual analysis.

Because the SST data are compiled principally from observations made by merchant and fishing vessels, the spatial and temporal distribution of data are concentrated along shipping lanes and over fishing grounds in the eastern tropical Pacific Ocean. SST data based on a 20-year mean (1948-1967) are used to provide background data in regions of sparse data. These data were computed from surface marine observations provided by the National Climatic Center, Asheville, North Carolina, through the cooperation of the NMFS Laboratory, La Jolla, California, Pacific Environmental Group, NMFS, Monterey, California, and the Fleet Numerical Weather

Central, U. S. Navy, Monterey, California. These long-term data are used also to prepare the monthly sea-surface temperature anomaly charts. The anomaly patterns are obtained by graphically subtracting the SST data from the long-term means for corresponding months.

This paper does not contain SST analyses for each month of the 1972-1973 El Niño. However, analyses for December 1971 and December 1972, representative of "cold" and "warm" years, respectively, are shown in Figure 1. The principal differences in the SST distribution between these "cold" and "warm" Decembers are most pronounced along the coast of South America and over the equatorial area. For example, monthly mean SSTs at shore stations along the South American coast ranged from about 59° to 61°F (15.0°-16.1°C) in December 1971 and from 63° to 72°F (17.2°-22.2°C) in December 1972. Also, in 1971 there was a strong thermal gradient in a narrow band 200-250 km wide parallel to the Peruvian shoreline and extending to about 2°S, where it abruptly turned eastward to intersect the coastline. The southern portion of the gradient was more diffuse and not as well defined as in the northern part. In 1972, by contrast, the thermal gradient was weaker and located farther south (mostly south of 10°S) than in 1971. Also the southern end of the gradient was better defined in 1972 than in 1971. In addition, the area of the eastern tropical Pacific occupied by waters with surface temperatures warmer than 80°F (26.7°C) was considerably greater in December 1972 than in December 1971.

Analyses of SSTs for other months are provided by Laurs (1972-1973). Surface temperatures, measured with bucket thermometers, from coastal stations between 5°S and 20°S provided by Living Marine Resources, Inc. (LMR), San Diego, California, were used to construct Figure 10.

Early in 1972, as sea temperatures began to rise, an attempt was made to monitor the broad-scale strength of the southeast trade winds off the coast of South America in relation to the surface warming in the Peru Current. Because reports of surface winds were very sparse along the coast, twice daily surface-pressure charts were used. From these charts, provided by the National Weather Service, Washington, D. C., a pressure gradient index was prepared. The gradient was obtained from the daily charts by subtracting the surface pressure at a coastal station in Peru near 16°S and a point at 30°S-90°W (approximately the center of the southeast Pacific high cell). Weekly averages of pressure gradient were plotted against the long-term mean pressure gradient between the same locations.

GENERAL INFORMATION ON EL NIÑO

To fishermen and coastal villagers of Central and South America, notably Ecuador and Peru, El Niño has meant unusually warm coastal waters, red tide, poor fishing, and frequent, torrential rains all culminating usually in December. Although El Niño is a colloquial term with a religious connotation (El Niño refers to the Christ child, a name chosen because of the culmination of this phenomenon near the traditional date of Christmas) its original meaning apparently is not known. Other names given to this abnormal oceanographic-meteorological phenomenon are: *El Pintor* or *Callao Painter* which refers to the blackening of the hulls of boats and of houses by hydrogen sulfide released from decomposition of marine organisms (Wooster, 1960); *Aguaje* which probably means both flooding from rains and occurrence of red tide which usually occurs simultaneously along Peru and Ecuador from December to February during El Niño years (A. Alvariño, NMFS, La Jolla, Calif., pers. comm.); and the *Corriente del Niño* or *Holy Child Current* identified by seafarers as a southward-moving current occurring near the end of the year, in contrast to the Peru Current which normally moves northward (James, 1953; Hawken, 1973).

In years of very weak El Niños or non-El Niño years, the cool Peru Current perpetuates a cold northward drift under extensive low, stratus clouds, a desert climate extends from Chile to southern Ecuador, and tropical rains are confined to the equatorial zone north of 5°S. In contrast, El Niño years are associated with a major shift in the atmospheric pressure systems extending from South America to at least the central South Pacific. Beginning in the southern winter of one year, extensive heat exchange from the warm coastal waters induces tropical-like rains and frequent flooding along coastal plains. This condition abates somewhat during the southern spring; but when coastal atmospheric pressures remain low heavy rains and sluggish southeast trade winds follow, and a second peak in the high sea temperature of the Peru Current occurs during the following summer. As the El Niño warming approaches its peak, the coastal fishery for anchovetas, *Engraulis ringens*, becomes erratic, with lower catches, while tropical species become more abundant and invade coastal waters to southern Peru at times (Wooster, 1960).

In the last 50 years, sea-surface temperature records reveal that El Niño conditions prevailed along the coast of South America in 1925, 1930, 1939, 1941, 1943, 1951, 1957, 1965, 1969 and 1972. There is an indication that there has been a 15- to 16-year cycle in the largest positive SST anomalies which have occurred at coastal stations in Peru and Ecuador during El Niño periods in 1925, 1941, 1957 (Berlage, 1966; Quinn and Burt, 1970), and most recently in 1972. Stevenson, *et al.* (1970) also noted that the literature indicated peaks in El Niño conditions at 6 and 16.5 years at coastal stations in Peru and Ecuador.

Literature regarding El Niños prior to the 1950's is primarily descriptive, and contains references to the warm Peru Current, primarily (Murphy, 1926; Schott, 1931; Gunther, 1936). Apparently, the evidence regarding the effects of warming on the physical properties of the Peru Current or the effects on the flora and fauna therein was limited to the immediate coastal areas.

HYPOTHESES ON THE ORIGIN OF EL NIÑO

Research on past El Niños suggests three general hypotheses on the origin of the relatively warm and low salinity water which periodically invades or is found at the surface of the Peru Current off South America during El Niño years. Currie (1953) and Bjerknes (1966) suggested that strong northerly winds sweep southward in the Gulf of Panama and east of the Galapagos Islands and the inter-tropical convergence zone is displaced into the southern hemisphere. This leads to a southward advection of the warm, low-salinity equatorial water and a breakdown of the equatorial ocean front off Ecuador when the southeast trade winds become weak off the coast of South America. Schott (1931) and James (1953) hypothesized an eastward advection of the warm water which is always found south of the Galapagos and west of the Peru Current. There is some evidence according to M. Tsuchiya (Scripps Institution of Oceanography, La Jolla, Calif., pers. comm.) to show that surface water can be displaced eastward between 5°S and 10°S where the South Equatorial Countercurrent may rise to the surface east of 110°W at times when the southeast trade winds decrease in the El Niño years. Stevenson *et al.* (1970) noted that on two occasions (April-June and October-December, 1965) warm surface water of high salinity penetrated to within 80 miles of the coast between 8°S and 10°S. They suggest that this eastward flow was associated with the South Equatorial Countercurrent, and that this current may have transported warm water very close to the coast during El Niño periods. According to Sears (1954) and Wooster (1960), when the southeast tradewinds decrease and vertical mixing or upwelling becomes minimal in the Peru Current and its equatorial extension, *in situ* heating occurs over the Peru Current because of less stratiform cloudiness. In addition, insolation is at a maximum during the southern hemisphere summer when El Niño conditions are most intense. It is known that larger amounts of rain fall from convective clouds over Ecuador and Peru and adjacent ocean regions of the Peru Current in warm years (Bjerknes, 1961). Greater amounts of moisture are carried into the atmosphere and fall out in the form of heavy showers. This may account, in part, for the areas of lower-salinity surface water which occur along the coast during an El Niño.

A discussion of the surface and subsurface ocean properties of the Peru Current during the 1965-1966 El Niño is presented by Stevenson *et al.* (1970). They also present a review of the literature regarding possible sources of warm water found along the coast of South America during El Niño years.

Wooster (1960) hypothesized that, "During El Niño years, there is a general weakening of the atmospheric circulation in the marine layer, and reduction in the wind-stress component parallel to the coast is responsible for a weakening or cessation of upwelling." He concludes that El Niño is a generic term with an application not only to the Peruvian coast but to the west coast areas of California, southwest Africa, western Australia, and Vietnam.

Bjerknes (1966) in discussing the weather ramifications of the 1957-1958 El Niño emphasized that, "El Niño is a summer phenomenon of the southern hemisphere and the high sea temperature measured in that season is a by-product of the annual insolation maximum, especially in the tradewind belt where there is little cloud . . . . Weakness of the tradewinds has more sudden and spectacular ocean effects in terms of temperature induced by the cessation of upwelling . . . . Whenever an area of upwelling water happens to be covered up by the invasion of warm surface water, the atmosphere is exposed to a new heat source creating vertical convection exchange and rainfall."

The presence of large pools of warm water between 5°S and 10°S during the southern summer was pointed out by Wyrtki (1964). He noted that detailed data and analyses revealed the existence of a warm tongue of water west of and adjacent to the cold Peru Current. Wyrtki emphasized that these isolated areas of higher temperatures could not be caused by advection, and that local heating was important because colder water usually surrounds the warm-water pockets during non-El Niño years. Sea-surface temperature analyses presented by Laurs (1972-1973) revealed that the warm-water areas described by Wyrtki extended eastward to the coast of Ecuador in the southern spring and summer of 1972. During cold years the warm-water areas usually remain 400 to 500 km off the coast. Wooster and Guillén (1974) also noted the warm tongue of water during the 1972-1973 El Niño.

Berlage (1966) suggests that the slowing down of the Peru Current is related to the "Southern Oscillation" wherein the atmospheric pressure in the southeast Pacific high-pressure cell decreases and the pressure becomes relatively high over Indonesia. In this situation the general atmospheric and hydrospheric circulations throughout the south Pacific Ocean are decelerated. Subsequently, the Peru Current becomes weaker, and relatively warm water along the Peru coast is fed into the South Equatorial Current. Berlage also explains that high pressures in the eastern part of the South Pacific and low pressures over Indonesia induce an accelerated "Southern Oscillation." In this case the Peru Current and southeast trade winds become stronger and sea-surface temperatures are reduced. Quinn and Burt (1970) also concluded that the El Niño is related to large-scale ocean-atmosphere anomalies associated with the Southern Oscillation which brings about unusual interhemispheric interactions in the equatorial Pacific. Periods of abnormally large amounts of rainfall over the equatorial dry zone west of 140°W have been associated with El Niño conditions that began earlier in the year east of the Galapagos Islands according to Quinn and Burt (1970, 1972).

OCEAN TEMPERATURE CONDITIONS DURING THE 1972-1973 EL NIÑO

Sea-surface temperature conditions over much of the eastern tropical Pacific during February 1972 to April 1973 followed a pattern in which (1) there was rapid warming from below-normal to above-normal temperatures, followed by (2) a slight shift to near-normal temperatures, then (3) a second period of rapid warming to well-above-normal temperatures which persisted for several months, and finally (4) a rapid return to normal or cooler-than-normal temperatures. In general, the changes in the sea-surface temperature patterns were more complex along the coast of South America and westward to the Galapagos Islands than they were farther offshore. Also, the rates of temperature change and their departure from normal were often larger along the coast than they were in offshore equatorial waters. The deviations from the long-term mean of sea-surface temperature over the eastern tropical Pacific for January 1972 through April 1973 are shown in Figures 2 through 9.

The initial warming period

Colder-than-normal ocean temperatures persisted generally over much of the eastern tropical Pacific from about late 1969 to January 1972 (anomaly chart for January 1972 shown in Figure 2a). A shift toward warmer ocean temperature conditions, which subsequently led to the 1972-1973 El Niño, was indicated in February 1972 (Figure 2b) when water temperatures 100 to 300 miles southeast of the Galapagos Islands increased as much as 6°F (3.3°C) from the previous month. Warming also weakened the below-normal temperature conditions which had persisted for many months along the equatorial zone westward to 145°W. The warming continued and was more prominent in March 1972 (Figure 3a) when positive temperature anomalies occurred in most of the equatorial zone from the coast of South America to 145°W. Negative deviations from the long-term mean persisted west of this longitude, but with reduced magnitudes. Temperatures in the areas off Guayaquil, Ecuador, and along the equator from 120°W to 140°W were 6°F (3.3°C) higher in March 1972 than in March 1971.

The warming trend which occurred in February and March 1972 appeared to be related to lighter-than-normal winds which reduced upwelling and to less-than-normal cloud cover, and to increased solar radiation.

These atmospheric conditions were associated with a southwestward shift of the southern hemisphere high pressure center and southward shift, by 5° of latitude, of the intertropical convergence.

A return toward normal

Higher-than-normal temperatures continued during April 1972 (Figure 3b) between South America and the Galapagos Islands from 5°N to 10°S and extended northward into the Gulf of Panama. However, no significant intensification of the warm condition occurred; in fact, temperatures close to shore along the Ecuadorian coast returned to near normal. During May (Figure 4a), sea-surface temperature along a narrow strip of the coast of South America from the equator to 10°S returned to near normal. Farther off the coast from about 80°W to 88°W temperatures remained above normal, but the magnitude of the deviation and the extent was not as large as during the prior month. Temperatures between 5°N and 5°S from the Galapagos Islands to 120°W were as much as 4°F (2.2°C) above normal.

The lowering of sea-surface temperatures along the South American coast during April and May 1972 was related to the partial re-establishment of the subtropical high-pressure center off South America and to the subsequent development of the southeast winds along the coast which apparently induced coastal upwelling. Offshore the southeast tradewinds remained weak and the warming along the equator appeared to be related to the relaxation of the upwelling that usually takes place there.

A second warming period

A second period of rapid warming began in June 1972 (Figure 4b). Pronounced warming took place along the coast of South America, out to 120°W, except for a small area off Ecuador. Between 80°W and 90°W temperatures were as much as 6°F (3.3°C) above normal. Extensive warming was also evident in the area west of 140°W between 5°S and 5°N and a bulge northward to the Hawaiian Islands between 160°W to 175°W. During July 1972 (Figure 5a) there was a marked increase in the area and intensity of the anomalously warm ocean temperatures. These prevailed along the coast of South America, except for a very small area off Lima, Peru, from below 10°S northward into the Gulf of Panama and in a continuous band along the equator to 180°W (and probably beyond). The magnitude of the positive deviations exceeded 8°F (4.4°C) in several areas along the equator from 100°W to the coast of South America.

The El Niño conditions continued during southern spring months and through January 1973, with anomalously warm waters occurring generally along the coast of South America and extending in a band between about 10°S and 10°N westward to 170°W (Figures 5b-8b). Between the coast and 90°W the positive anomalies ranged from 2° to 8°F (1.1°-4-4°C) with values of 4° to 6°F (2.2-3.3°C) predominating during most months. There were also periods when in certain coastal regions monthly mean temperatures returned to normal, *e.g.* off northern Peru and Ecuador in October 1972 (Figure 6b), and off central Peru in November 1972 (Figure 7a). In waters along the equatorial zone between 10°S and 10°N and westward of 90°W the positive temperature anomalies ranged from 2° to 8°F (1.1°-4.4°C) with values of about 4°F (2.2°C) predominating. There was a northward expansion of the warm-water anomaly over much of the eastern tropical Pacific during October to December 1972 (Figures 6b and 7b) with 2° to 4°F (1.1°-2.2°C) positive deviations observed off the coast of Mexico. The magnitude of the anomaly during September 1972 (Figure 6a) was slightly less than that during the preceding or succeeding months. This appeared to be related to the partial re-establishment of the southeast tradewinds which caused upwelling and air-sea interaction processes to slightly cool ocean waters.

An End to El Niño conditions

During February 1973 (Figure 8b) the extent and magnitude of the positive temperature anomaly decreased markedly from what it had been during the previous several months, and it was apparent that the El Niño was nearing an end. Water temperatures in a narrow strip along the South American coast, except for a small area off northern Peru and Ecuador, had returned to normal or slightly below normal. Also the band of anomalously warm water which had extended for several months along the equator was broken between about 120°W to 145°W. The magnitude of the anomaly had decreased for the most part to about 2°F (1.1°C) above normal, with only small areas reaching 4°F (2.2°C) above normal. By March 1973 (Figure 9a) only small broken patches of anomalously warm water remained. The El Niño had ended by April 1973 (Figure 9b), when normal or below-normal ocean temperature conditions were apparent along most of the coast of South America and in the offshore equatorial zone.

SIMILARITIES IN OCEAN TEMPERATURE DURING RECENT EL NIÑOS

While the intensity, duration, and areas of maximum influence show some variation, coastal and island station SST data indicate that the trends of the anomaly patterns in ocean temperature have been similar during periods of well-developed El Niños.

Figure 10 is a time section of SST anomalies based on data for Puerto Chicama, Peru, from January 1925 to January 1969 obtained from LMR. After January 1969 the data for Chimbote, Peru, were used and statistically adjusted for Puerto Chicama. These data are considered to be representative of coastal sea-surface temperature conditions along the coast of Ecuador and Peru. In Figure 10 the data have been realigned to show similarities in anomaly patterns during the more pronounced El Niño years; therefore there are interruptions or repetitions in the data in some years. Several features are evident from Figure 10. In most cases, except 1930 and 1939 to 1941, the southern spring and summer preceding an El Niño were much colder than usual, with coastal waters off Peru significantly below the long-term mean for periods of more than 12 months. Also, the positive anomalies for the strong El Niño years of 1925, 1941, 1957, 1965, and 1972 were all bimodal. One anomaly peak occurred in the fall or early winter and another occurred at the end of the year or the beginning of the next. In the weaker El Niño years of 1930, 1943, 1951, 1953, and 1969, one of the anomaly peaks, usually the one occurring in the southern summer (December-January), was either depressed or absent. By September or October of both strong and weak El Niño years, the positive anomaly reached a minimum value. This occurs in the southern spring when sea-surface temperatures in the Peru Current are at a minimum. During the 1972-1973 El Niño maximum, positive anomalies at Puerto Chicama (Chimbote) occurred in May 1972, 5.8°F (3.2°C) and December 1973, 8.3°F (4.6°C), and the minimum positive anomaly occurred in October 1972, 2.0°F (1.1°C).

Bimodal peaks in the positive SST anomalies which are similar for 1957, 1965, and 1972 are graphically portrayed in Figure 10. Because of the apparent similarities among these three warm years, it is appropriate to examine in greater detail than is shown in Figure 10 seasonal SST profiles for other South American coastal and equatorial stations. In addition, the departures of each yearly temperature profile from the long-term mean are reviewed in the following paragraphs.

In Figures 11 and 12 are shown the seasonal changes in sea-surface temperatures and their departures from long-term means for 1957-1958, 1965-1966, and 1972-1973 for two South American coastal stations and two equatorial island stations. The mean seasonal curves have been constructed from data published by the National Ocean Survey (NOS) for Pacific island and coastal stations (Jones, 1970). The 1957 and 1965 data for Chimbote, Peru (9°S), Arica, Chile (18°S), Christmas Island (2°N-157°W), and San Cristobal, Galapagos Islands (2°S-90°W), were obtained from the NOS publication. During 1972 SST data for Chimbote and Ilo, Peru (Ilo is near Arica, Chile, which had no 1972 SST data), were provided by LMR. Because SST data for the two equatorial island stations (Figure 12) were not complete in 1972, estimates of the monthly SST values, based on long-term means and anomalies at each place, have been determined from the monthly analyses of Laurs (1972).

From Figure 11 it can be seen that the SSTs in 1957-1958 remained well above the mean for the entire period at Chimbote and above the mean after February at Ilo. During 1965 the SST profiles were similar to those in 1957. In 1972 the SST values at each station remained below or near the long-term mean until April or May. Thereafter they continued above the long-term mean until October, when the SSTs decreased to the long-term mean at Chimbote and below the mean at Ilo. As the southern summer (October) approached, SSTs north of 10° S increased faster than the long-term mean and reached a peak in January 1973. It is estimated that the largest departure from the long-term mean was reached along the coast south of Guayaquil (5°S), where the anomaly was about +9° F (5°C) in January 1973.

In Figure 12, a small annual SST variation at Christmas Island and a large one at San Cristobal (Galapagos Islands) are evident. In all three El Niño years the SST curves were above the mean in the Galapagos area in February, and they did not return to the mean until after February of the following year. In the Galapagos Islands area the 1972 and 1965 departures from the mean were very similar to those in 1957-1958. At Christmas Island the significant departures of SSTs from the mean took place after June. Quinn and Burt (1970) emphasized the delayed warming at Christmas Island.

ATMOSPHERIC INFLUENCE OF THE 1972 EL NIÑO

During periods of El Niño there are periodic relaxations or decreases in speed of the southeast tradewinds off South America, particularly south of 15°S, which result in a decrease in the surface wind stress needed to maintain vertical mixing and upwelling in the relatively weak Peru Current. This phenomenon is related to large-scale changes in the atmospheric circulation whereby the subtropical high-pressure center near 30°S-90°W is frequently displaced by storms which move closer to the equator in El Niño years. Near the mainland variations in coastline configurations combined with local land-sea thermal gradients may create conditions more or less favorable for local wind stresses and vertical ocean mixing. In warm years coastal thermal gradients and local winds are weakened in an already sluggish southeast tradewind regime. Vertical mixing in the Peru Current is markedly reduced and surface layers are no longer cooled effectively by cooler, deeper water.

Because the atmospheric circulation over the South Pacific plays an important role in maintaining or diminishing wind-induced upwelling in the Peru Current, variations in the sea-surface pressure gradient were examined between 30°S-90°W, near the climatological center of the southeast Pacific high cell, and a station on the coast of Peru at 16°S. The anomalies in the pressure gradient provided a weekly index of the general strength of the southeast tradewinds over part of the Peru Current. Pressure data were extracted from global, surface pressure charts prepared twice daily by the National Weather Service (NWS), Washington, D. C.

During the 1972-1973 El Niño, two principal surface-pressure patterns prevailed over the eastern part of the south Pacific. For periods of 7 to 14 days the southeast tradewinds were relatively steady and strong. In Figure 13a is shown a surface-pressure analysis prepared by the NWS in which the southeast Pacific subtropical high pressure center was the dominant feature off the coast of South America during the middle part of July 1972. Pressure patterns of this type produced pressure gradients typical of those periods when the southeast tradewinds south of 15°S were of sufficient strength to induce vertical mixing and maintain upwelling in the Peru Current. In contrast, there were frequent periods of 15 to 20 days in 1972-1973 when low-pressure centers and weather fronts moved toward the coast between 20°S and 30°S. An example of this situation is shown in Figure 13b. Successive passages of low-pressure areas eastward past 30°S-90°W caused a breakdown in the subtropical high-pressure center over the southeast Pacific and the southeast tradewinds were markedly diminished. During cold or non-El Niño years, weather fronts and low-pressure centers usually swing poleward near 30°S and west of 100°W, and the southeast high remains intense. Wooster and Guillén (1974) pointed out that at Lima, Peru, and elsewhere along the coast, surface pressures were lower than normal in 1972, which was consistent with the southward displacement of the inter-tropical convergence zone during El Niño periods. It appears that in 1972 the weather systems had more equatorward trajectories because most probably the major upper-air steering currents or jet streams over the southern hemisphere were shifted out of their usual positions most of the year. Recently Krueger and Winston (1974) examined anomalies in the equatorial flow of the upper air over the eastern Pacific. They showed that the equatorial easterlies were usually weak from the surface through 700 mb (about 3.5 km), and the southeast tradewinds were reduced south of 20°S off the coast of South America in association with increased (anomalous) cyclonic stream flow west of 90°W at the 700-mb level. Namias (1972) noted that in the North Pacific, based on 20 years of data (1947-1966), the 700-mb height anomalies and SST anomalies have high negative correlations, and that similar teleconnections exist over the Pacific between the sea-surface temperatures and the 700-mb heights.

Figure 14a shows that alternating periods of above-normal and below-normal pressure gradients occurred frequently off the coast of South America beginning in January 1972. Apparently, the large reduction in pressure between 30°S-90°W and the coast of northern Chile and Central Peru during March, April, June, August, and November 1972, caused enough relaxation in the southeast tradewinds to keep upwelling to a minimum in the Peru Current, even though there were also shorter periods when the pressure gradient was well above normal. Monthly mean pressures from the 1957-1958 International Geophysical Year revealed a reduction in the pressure gradients off South America similar in time to those in 1972 (Figure 14).

If the pressure gradient data for 1972-1973 shown in Figure 14a are averaged over each month the resultant curve, showing departure from the normal (long-term mean) pressure gradient, shows seasonal changes similar to the 1957-1958 pressure gradient curve. Although the pressure gradient index in Figure 14 provides only a crude index of the strength of the southeasterlies off South America, it does indicate that frequent interruptions or relaxations of the wind stress on the Peru Current occur in El Niño years, and that these relaxations are reflected in the sea-surface temperatures of South American coastal stations.

In Figure 14b, the departures of SST from the long-term mean SST at Puerto Chicama are displayed to show the correspondence with fluctuations in the pressure gradient. Large negative SST departures appear to follow an above-normal pressure gradient in the late 1971 southern summer season. A sharp increase in the SST at Puerto Chicama is evident after mid-February, corresponding in time to large, negative-pressure departures off the coast of South America. Thereafter, the pressure gradient relaxed for long periods, particularly in June and August 1972 (Figure 14a). The largest SST departures from the long-term mean are found during this period (Figure 14b). After September the periods of weaker southeast tradewinds were much shorter, and the SST was near normal until late November. The second and most pronounced warming occurred in December, following a sharp reduction in pressure gradient. At this time two short increases in pressure gradient apparently reflected only temporary increases in the southeast tradewinds. The end of coastal warming and start of rapid cooling are apparent after February 1973, 1 year after the El Niño began.

CONCLUDING REMARKS

In 1972-1973, as in other El Niño periods, the ocean warming trend began in the Peru Current area off Ecuador and Peru and spread westward and poleward in both hemispheres with the onset of southern winter. By this time, the major high-pressure troughs and ridges apparently shifted from their normal positions, in the southern hemisphere allowing a succession of mid-latitude low-pressure systems to penetrate into the tropics of the southern hemisphere. This resulted in a reduction in surface-pressure gradients over a large portion of the eastern south Pacific and consequent slackening of the southeast tradewinds along the coast of South America, north of 15°S, and across the equator. Due to the relaxation of the southeast tradewinds, upwelling was diminished and other air-sea interaction processes were affected to the extent that the surface of the Peru Current and its equatorial extension warmed to above-normal temperatures.

The cause(s) of the anomalous changes in the ocean and atmosphere over the South Pacific is (are) not entirely understood, and much research is required to determine the extent of ocean-atmosphere exchange during an El Niño. It is quite probable that once the equatorial warming begins, the atmosphere becomes transformed locally by the increased sensible heat available from the ocean. As a result, low cloudiness diminishes over the Peru Current and a greater amount of solar energy reaches the ocean surface.

In the future, satellites positioned over the equatorial area should be able to assist in the detection of the onset and extent of El Niños by frequently collecting data on the earth's temperature and clouds. For example, satellite data from ATS3 and NOAA2 revealed a significant reduction in low-level stratus clouds along the coasts of Ecuador and northern Peru during the 1972-1973 El Niño. Thin strato-cumulus clouds with large breaks in the cloud cover were usually seen from satellite photographs in 1972, when the positive SST anomalies were large along the coast of South America. At times when the Peru Current region was cool, a thick layer of stratus clouds usually extended westward and equatorward over the cold water. Quinn and Burt (1970) also pointed out the potential use of satellite data in monitoring El Niño conditions.

The 1972-1973 El Niño was intense, and its effects were widespread along the South American coast. For example, weather and fishing for anchoveta were apparently affected markedly by the warm-water conditions. Along the coast of South America heavy tropical rains began falling in December 1971 and spread southward as the El Niño developed. At Guayaquil, Ecuador, rainfall averaged 11 inches (275 mm) per month between January and April 1972, which is 10 times the normal monthly rainfall. Tropical rains abated somewhat during April and May from Ecuador to Peru, but increased again sharply in June along the coast of central Peru. There was another lull in tropical rains from August to November. However, as the ocean temperatures of the Peru Current rose to a high in December 1972 and January 1973, tropical rains resumed again (701 mm fell at Guayaquil in January 1973) and caused much flooding in Peru and Ecuador.

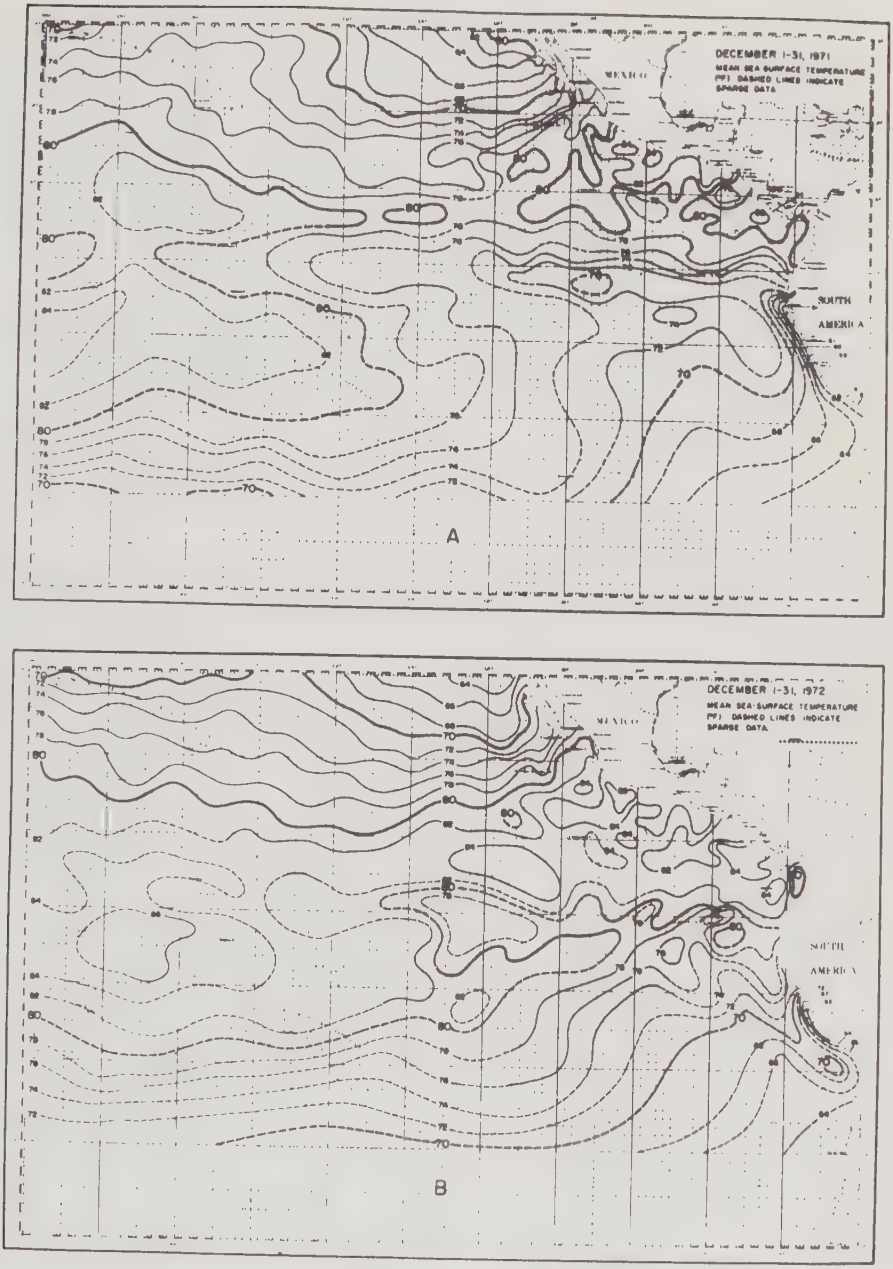
DECEMBER 1-31, 1971
MEAN SEA SURFACE TEMPERATURE (°F) DASHED LINES INDICATE SPARSE DATA
MEXICO
SOUTH AMERICA
A
DECEMBER 1-31, 1972
MEAN SEA-SURFACE TEMPERATURE (°F) DASHED LINES INDICATE SPARSE DATA
MEXICO
SOUTH AMERICA
B

FIGURE 1. Sea-surface temperature analyses for December 1971 (A) and December 1972 (B) based on monthly mean temperatures from ships, averaged by 1-degree quadrangles and monthly mean sea-surface temperatures from available coastal stations in Ecuador and Peru.

FIGURA 1. Análisis de la temperatura superficial del mar de diciembre 1971 (A) y diciembre de 1972 (B) basado en las temperaturas medias mensuales tomadas por los barcos, promediadas por cuadrángulos de 1 grado y la media mensual de las temperaturas de la superficie del mar obtenida en estaciones costeras del Ecuador y Perú.

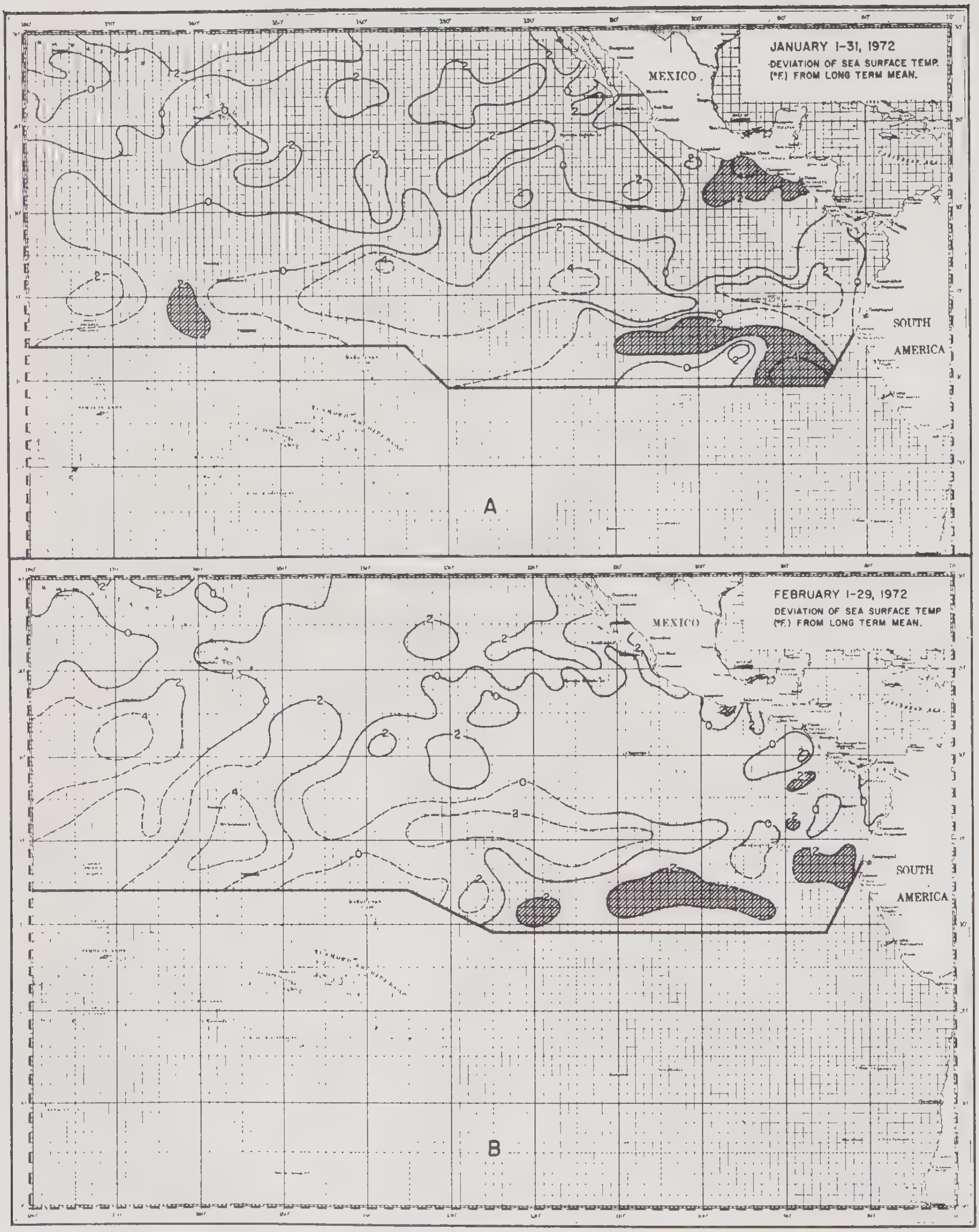
JANUARY 1-31, 1972
DEVIATION OF SEA SURFACE TEMP. (°F.) FROM LONG TERM MEAN.
MEXICO
SOUTH AMERICA
A
FEBRUARY 1-29, 1972
DEVIATION OF SEA SURFACE TEMP (°F.) FROM LONG TERM MEAN.
MEXICO
SOUTH AMERICA
B

FIGURE 2. Monthly sea-surface temperature anomalies (deviations from the 1947-1968 mean temperatures) for January 1972 (A) and February 1972 (B). Shaded areas were warmer by 2°F (1.1°C) or more than the long-term means.

FIGURA 2. Anomalías mensuales de la temperatura superficial del mar (desviaciones de la media de las temperaturas de 1947-1968) de enero 1972 (A) y febrero de 1972 (B). Las áreas sombreadas tenían 2°F (1.1°C) o más de temperatura que las medias a largo plazo.

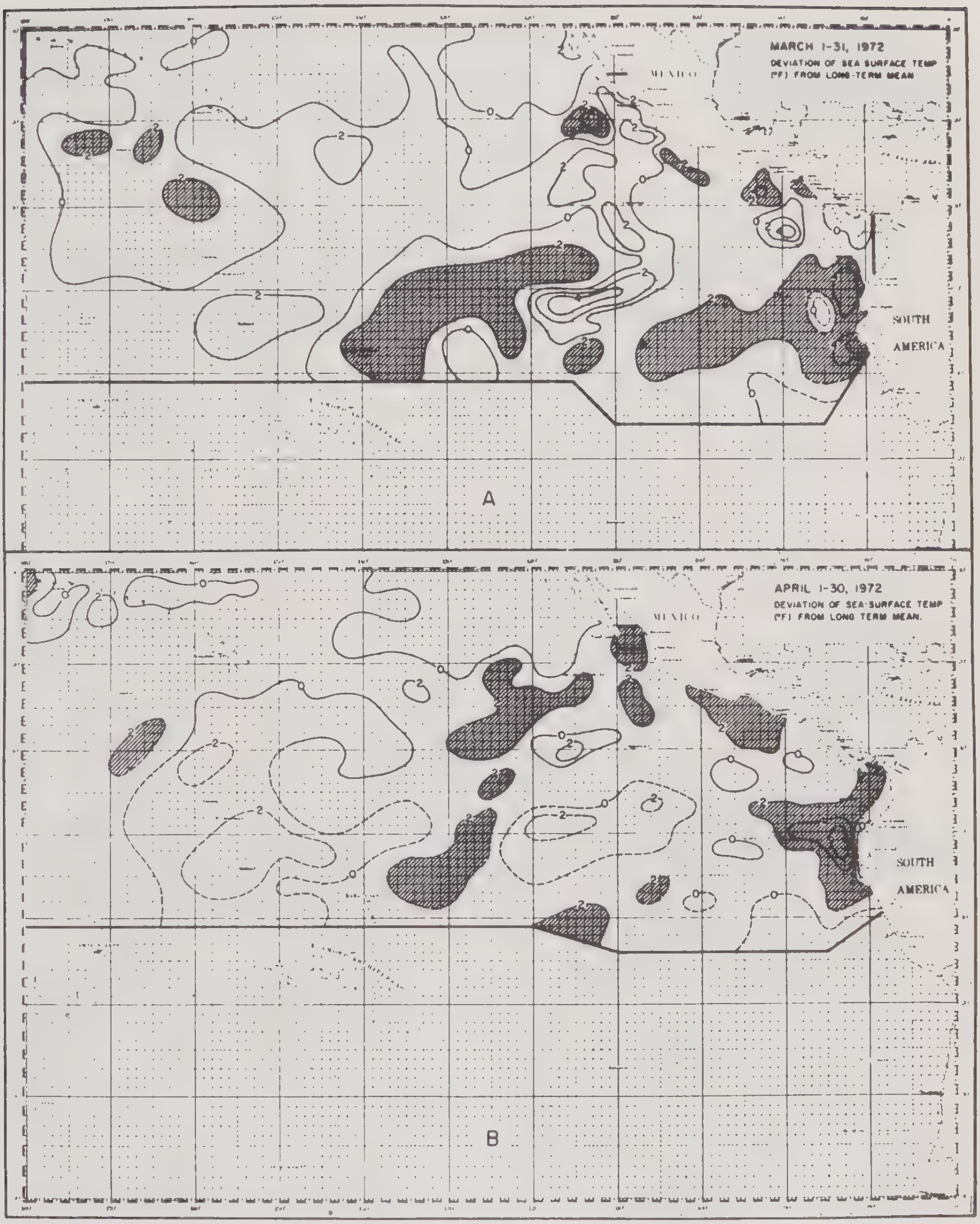
MARCH 1-31, 1972
DEVIATION OF SEA SURFACE TEMP (°F) FROM LONG-TERM MEAN
MEXICO
SOUTH AMERICA
A
APRIL 1-30, 1972
DEVIATION OF SEA-SURFACE TEMP (°F) FROM LONG TERM MEAN.
MEXICO
SOUTH AMERICA
B

FIGURE 3. Monthly sea-surface temperature anomalies (deviations from the 1947-1968 mean temperatures) for March 1972 (A) and April 1972 (B). Shaded areas were warmer by 2°F (1.1°C) or more than the long-term means.

FIGURA 3. Anomalías mensuales de la temperatura superficial del mar (desviaciones de la media de las temperaturas de 1947-1968) de marzo 1972 (A) y abril 1972 (B). Las áreas sombreadas tenían 2°F (1.1°C) o más de temperatura que las medias a largo plazo.

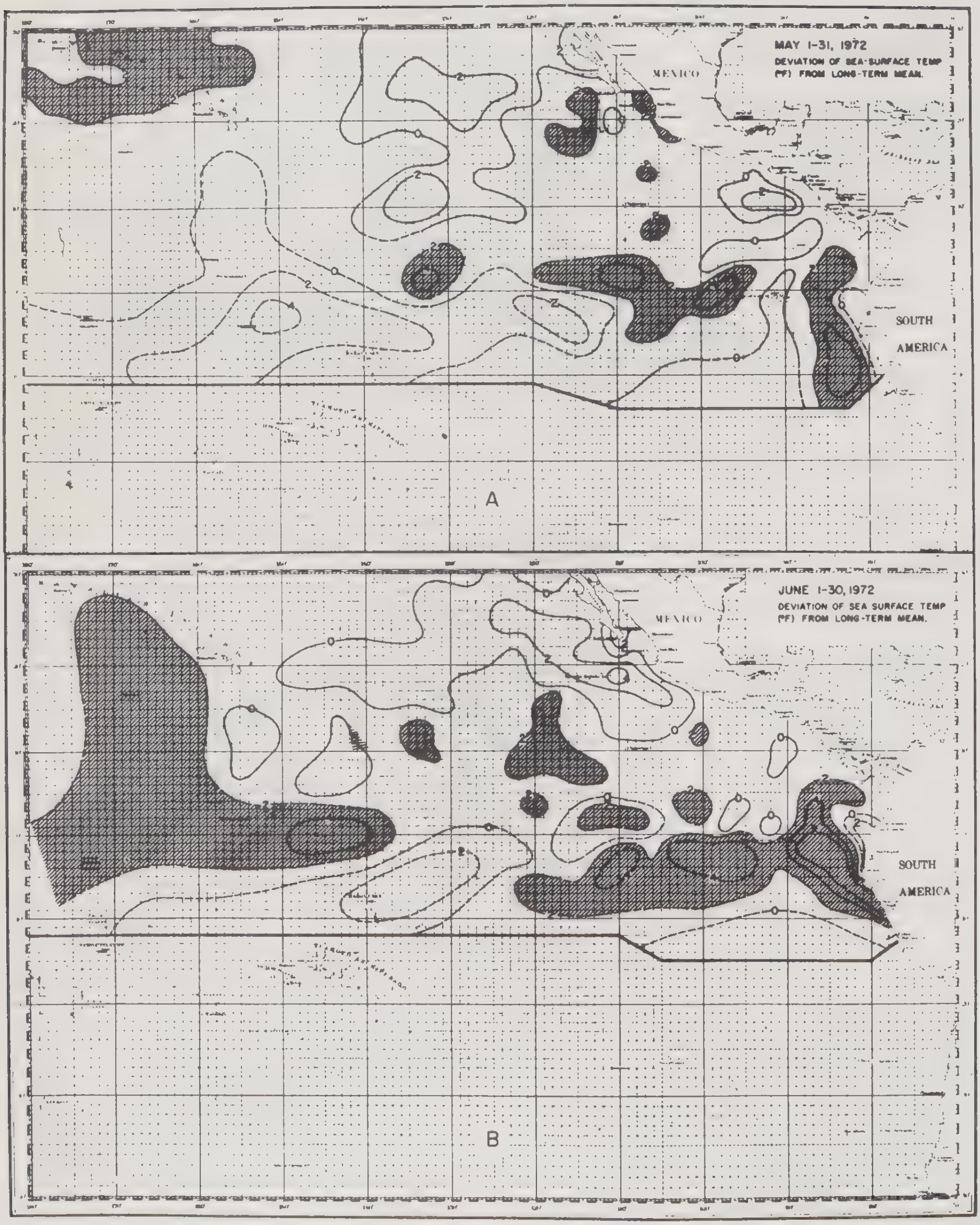
MAY 1-31, 1972
DEVIATION OF SEA-SURFACE TEMP (°F) FROM LONG-TERM MEAN.
MEXICO
SOUTH AMERICA
A
JUNE 1-30, 1972
DEVIATION OF SEA SURFACE TEMP (°F) FROM LONG-TERM MEAN.
MEXICO
SOUTH AMERICA
B

FIGURE 4. Monthly sea-surface temperature anomalies (deviations from the 1947-1968 mean temperatures) for May 1972 (A) and June 1972 (B). Shaded areas were warmer by 2°F (1.1°C) or more than the long-term means.

FIGURA 4. Anomalías mensuales de la temperatura superficial del mar (desviaciones de la media de las temperaturas de 1947-1968) de mayo 1972 (A) y junio 1972 (B). Las áreas sombreadas tenían 2°F (1.1°C) o más de temperatura que las medias a largo plazo.

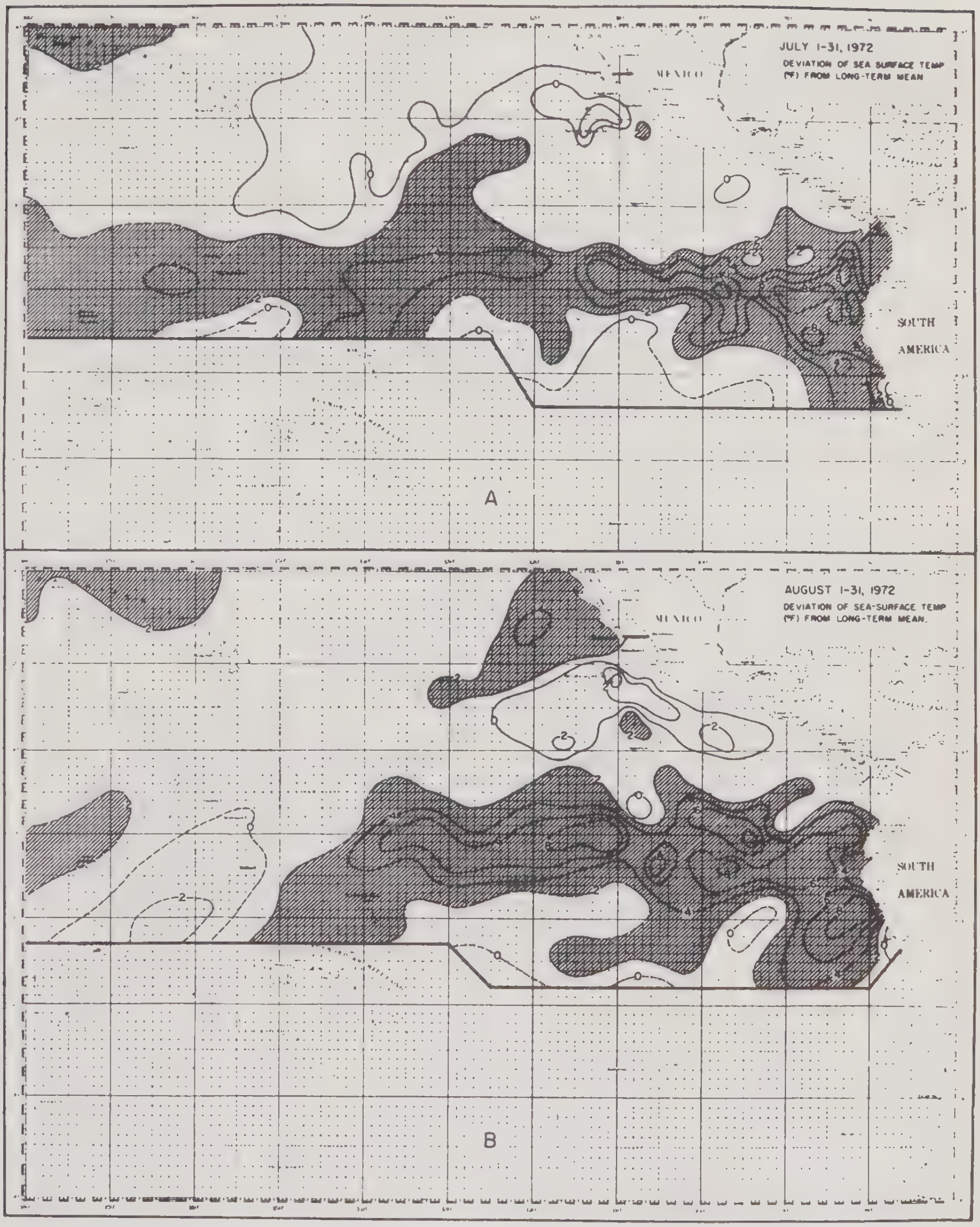
JULY 1-31, 1972
DEVIATION OF SEA SURFACE TEMP (°F) FROM LONG-TERM MEAN
MEXICO
SOUTH AMERICA
A
AUGUST 1-31, 1972
DEVIATION OF SEA-SURFACE TEMP (°F) FROM LONG-TERM MEAN.
MEXICO
SOUTH AMERICA
B

FIGURE 5. Monthly sea-surface temperature anomalies (deviations from the 1947-1968 mean temperatures) for July 1972 (A) and August 1972 (B). Shaded areas were warmer by 2°F (1.1°C) or more than the long-term means.

FIGURA 5. Anomalías mensuales de la temperatura superficial del mar (desviaciones de la media de las temperaturas de 1947-1968) de julio 1972 (A) y agosto 1972 (B). Las áreas sombreadas tenían 2°F (1.1°C) o más de temperatura que las medias a largo plazo.

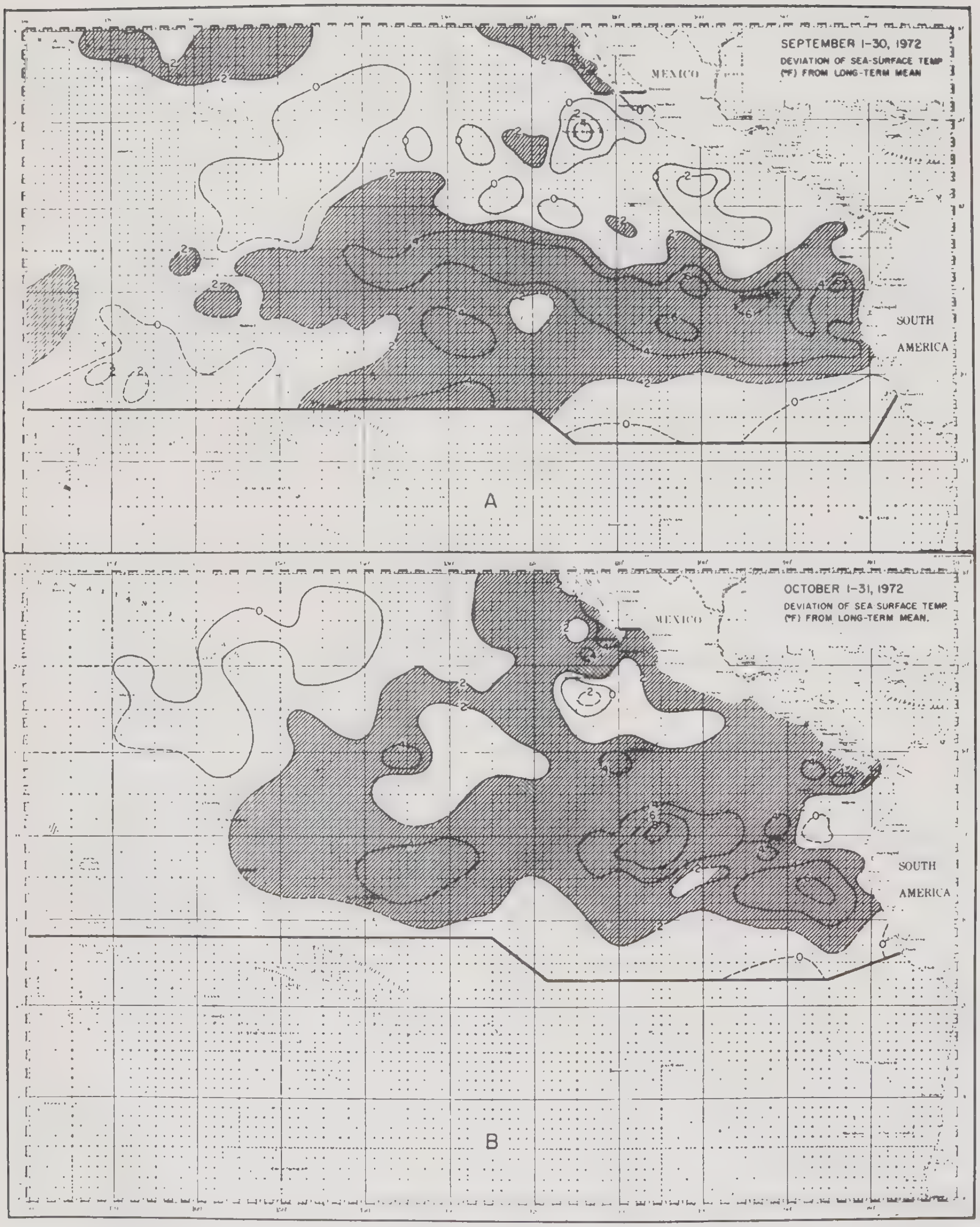
SEPTEMBER 1–30, 1972
DEVIATION OF SEA-SURFACE TEMP (°F) FROM LONG-TERM MEAN
MEXICO
SOUTH AMERICA
A
OCTOBER 1–31, 1972
DEVIATION OF SEA SURFACE TEMP. (°F) FROM LONG-TERM MEAN.
MEXICO
SOUTH AMERICA
B

FIGURE 6. Monthly sea-surface temperature anomalies (deviations from the 1947-1968 mean temperatures) for September 1972 (A) and October 1972 (B). Shaded areas were warmer by 2°F (1.1°C) or more than the long-term means.

FIGURA 6. Anomalías mensuales de la temperatura superficial del mar (desviaciones de la media de las temperaturas de 1947-1968) de septiembre 1972 (A) y octubre 1972 (B). Las áreas sombreadas tenían 2°F (1.1°C) o más de temperatura que las medias a largo plazo.

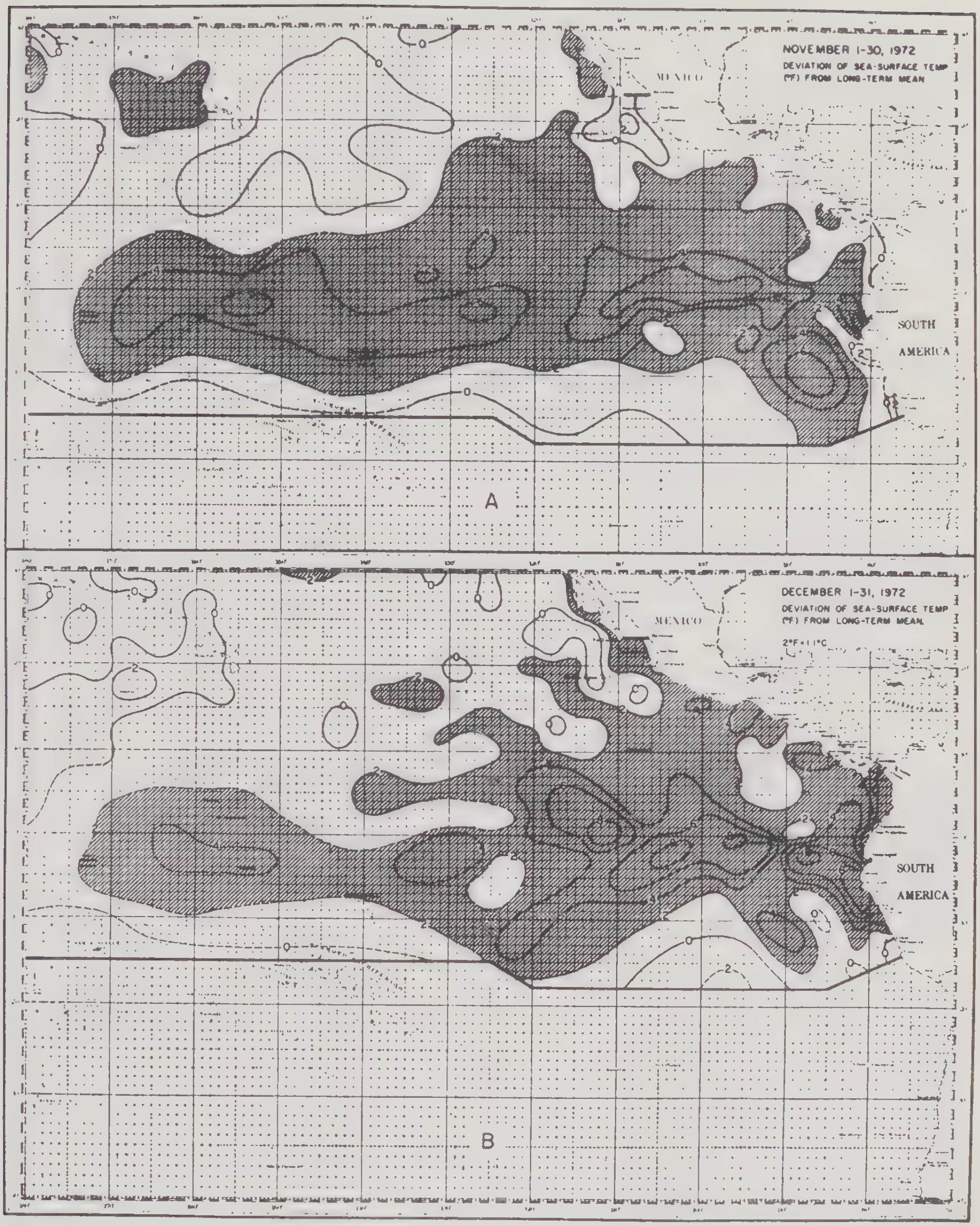
NOVEMBER 1-30, 1972
DEVIATION OF SEA-SURFACE TEMP (°F) FROM LONG-TERM MEAN
MEXICO
SOUTH AMERICA
A
DECEMBER 1-31, 1972
DEVIATION OF SEA-SURFACE TEMP (°F) FROM LONG-TERM MEAN
2°F = 1.1°C
MEXICO
SOUTH AMERICA
B

FIGURE 7. Monthly sea-surface temperature anomalies (deviations from the 1947-1968 mean temperatures) for November 1972 (A) and December 1972 (B). Shaded areas were warmer by 2°F (1.1°C) or more than the long-term means.

FIGURA 7. Anomalías mensuales de la temperatura superficial del mar (desviaciones de la media de las temperaturas de 1947-1968) de noviembre 1972 (A) y diciembre 1972 (B). Las áreas sombreadas tenían 2°F (1.1°C) o más de temperatura que las medias a largo plazo.

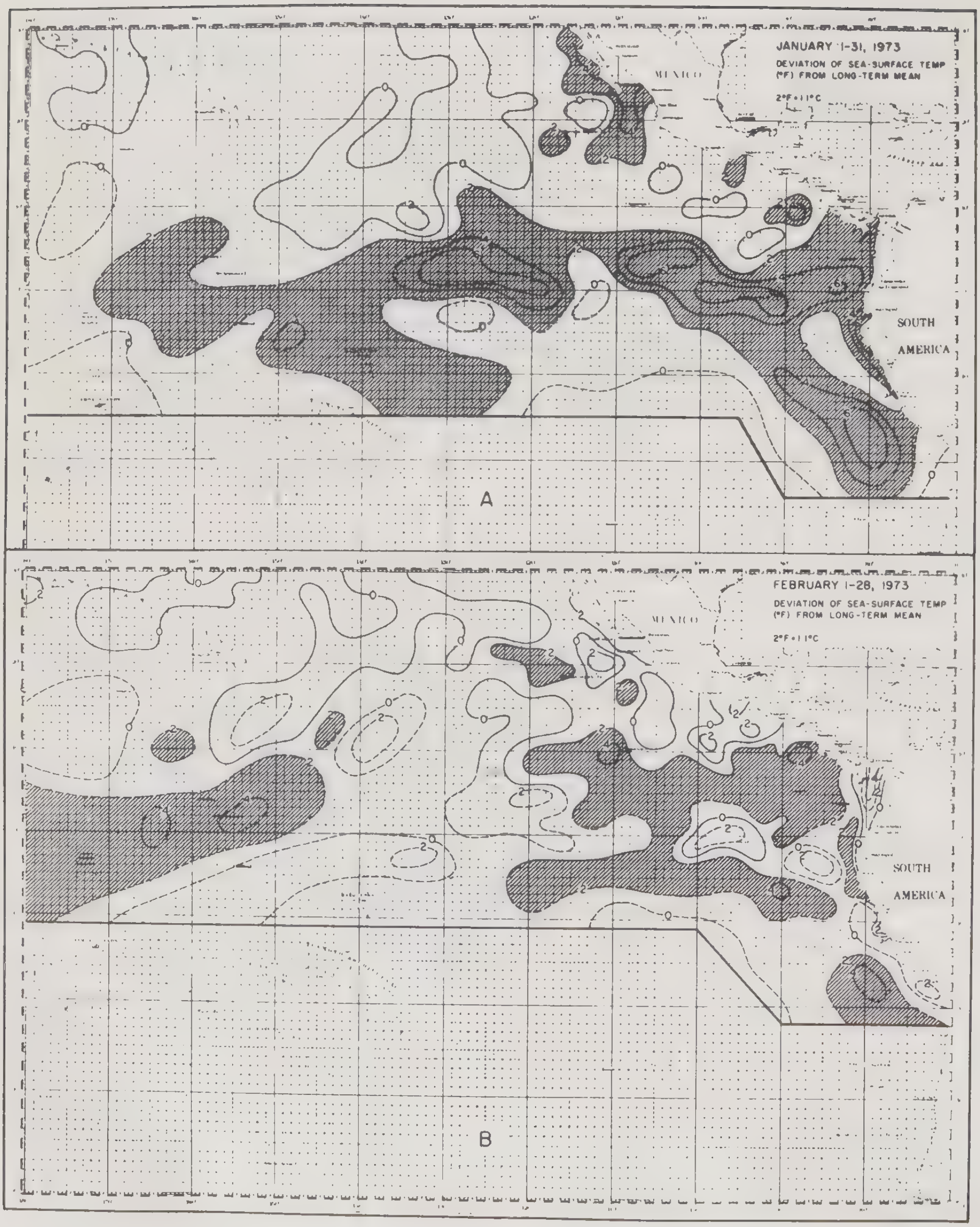
JANUARY 1-31, 1973
DEVIATION OF SEA-SURFACE TEMP (°F) FROM LONG-TERM MEAN
2°F = 1.1°C
MEXICO
SOUTH AMERICA
A
FEBRUARY 1-28, 1973
DEVIATION OF SEA-SURFACE TEMP (°F) FROM LONG-TERM MEAN
2°F = 1.1°C
MEXICO
SOUTH AMERICA
B

FIGURE 8. Monthly sea-surface temperature anomalies (deviations from the 1947-1968 mean temperatures) for January 1973 (A) and February 1973 (B). Shaded areas were warmer by 2°F (1.1°C) or more than the long-term means.

FIGURA 8. Anomalías mensuales de la temperatura superficial del mar (desviaciones de la media de las temperaturas de 1947-1968) de enero 1973 (A) y febrero 1973 (B). Las áreas sombreadas tenían 2°F (1.1°C) o más de temperatura que las medias a largo plazo.

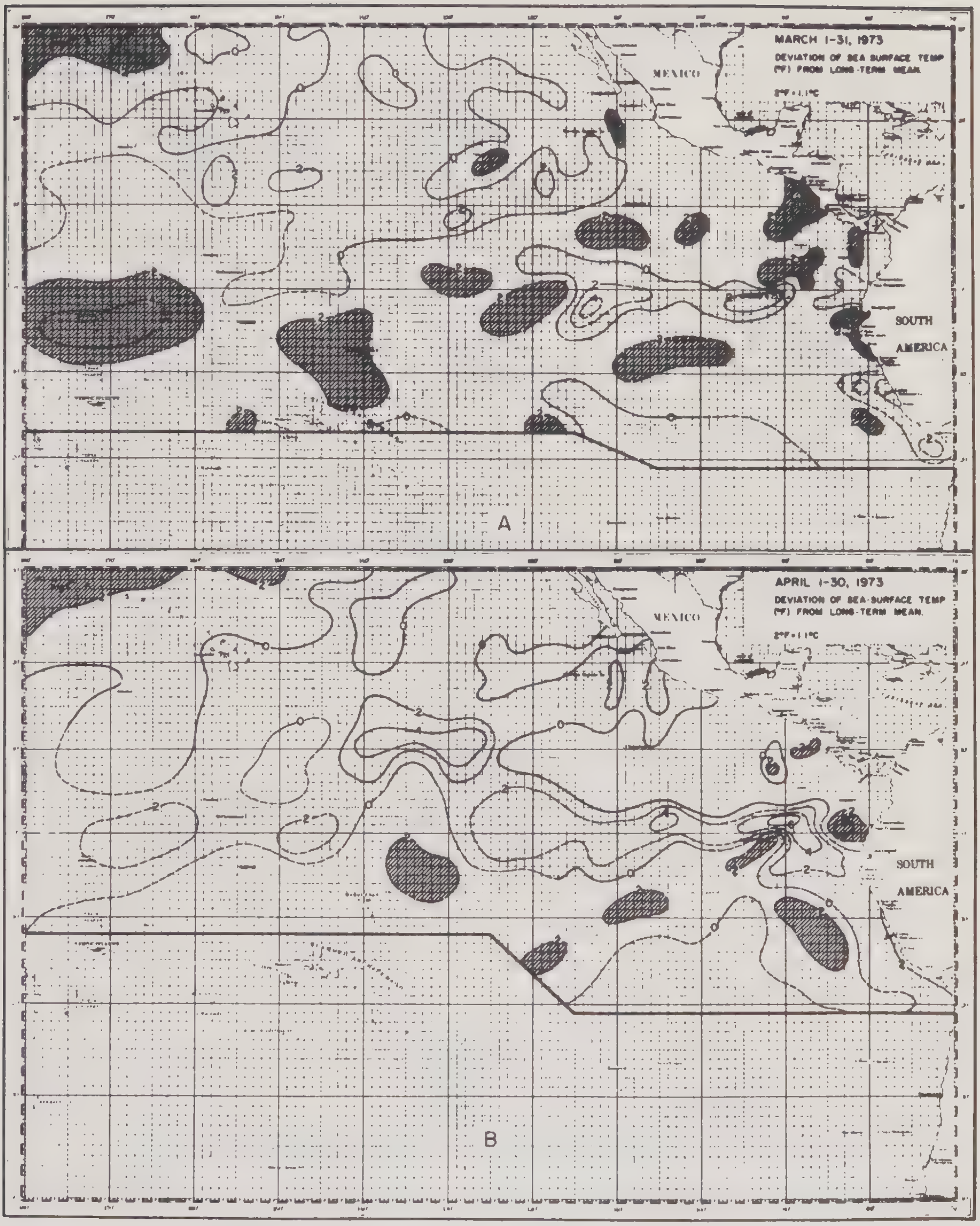
MARCH 1-31, 1973
DEVIATION OF SEA SURFACE TEMP (°F) FROM LONG-TERM MEAN
2°F=1.1°C
MEXICO
SOUTH AMERICA
A
APRIL 1-30, 1973
DEVIATION OF SEA-SURFACE TEMP (°F) FROM LONG-TERM MEAN.
2°F=1.1°C
MEXICO
SOUTH AMERICA
B

FIGURE 9. Monthly sea-surface temperature anomalies (deviations from the 1947-1968 mean temperatures) for March 1973 (A) and April 1973 (B). Shaded areas were warmer by 2°F (1.1°C) or more than the long-term means.

FIGURA 9. Anomalías mensuales de la temperatura superficial del mar (desviaciones de la media de las temperaturas de 1947-1968) de marzo 1973 (A) y abril 1973 (B). Las áreas sombreadas tenían 2°F (1.1°C) o más de temperatura que las medias a largo plazo.

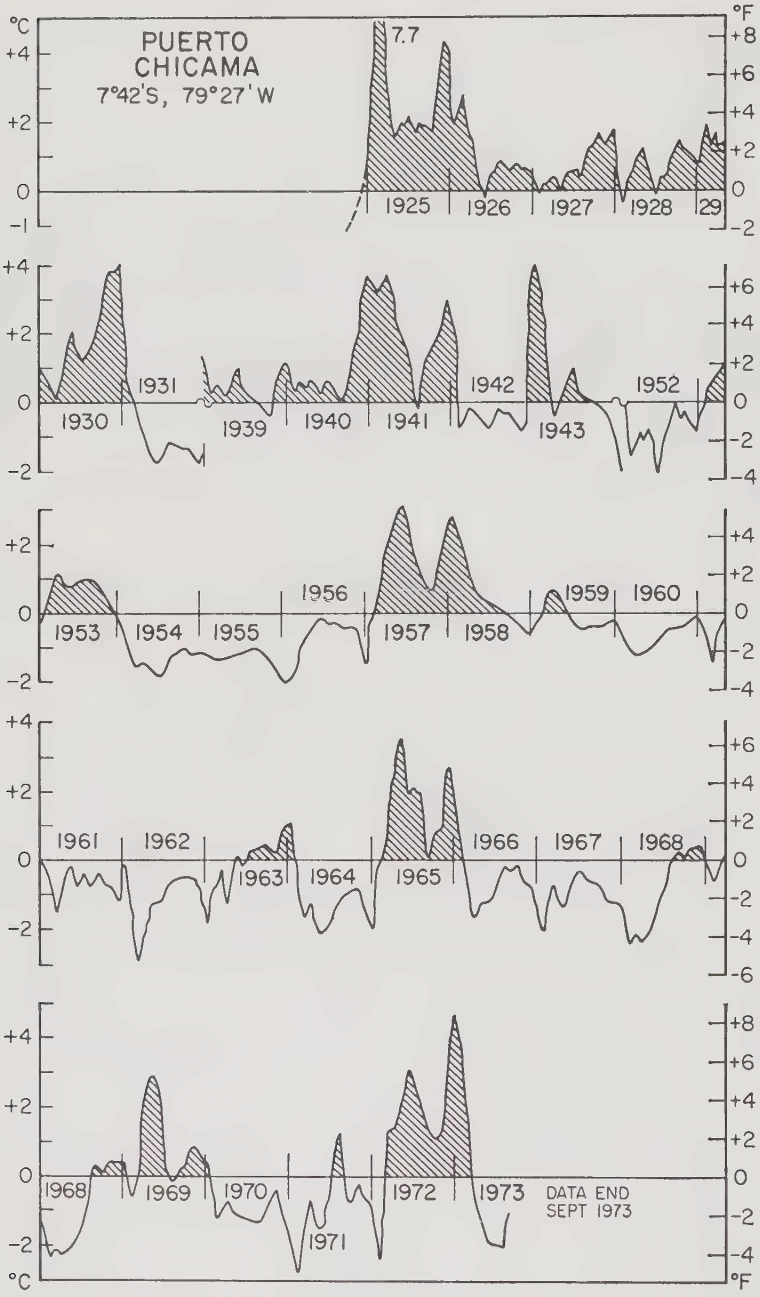

FIGURE 10. Time sections of sea-surface temperature anomalies (C°) at Puerto Chicama, Peru. Positive anomalies are hatched. For alignment of major El Niño periods there are periodic data gaps or overlaps in the sections.

FIGURA 10. Secciones cronológicas de las anomalías de la temperatura superficial del mar (°C) en Puerto Chicama, Perú. Las anomalías positivas se encuentran sombreadas por líneas. Para la alineación de períodos principales del Niño hay vacíos periódicos de los datos o éstos se sobreponen en las secciones.

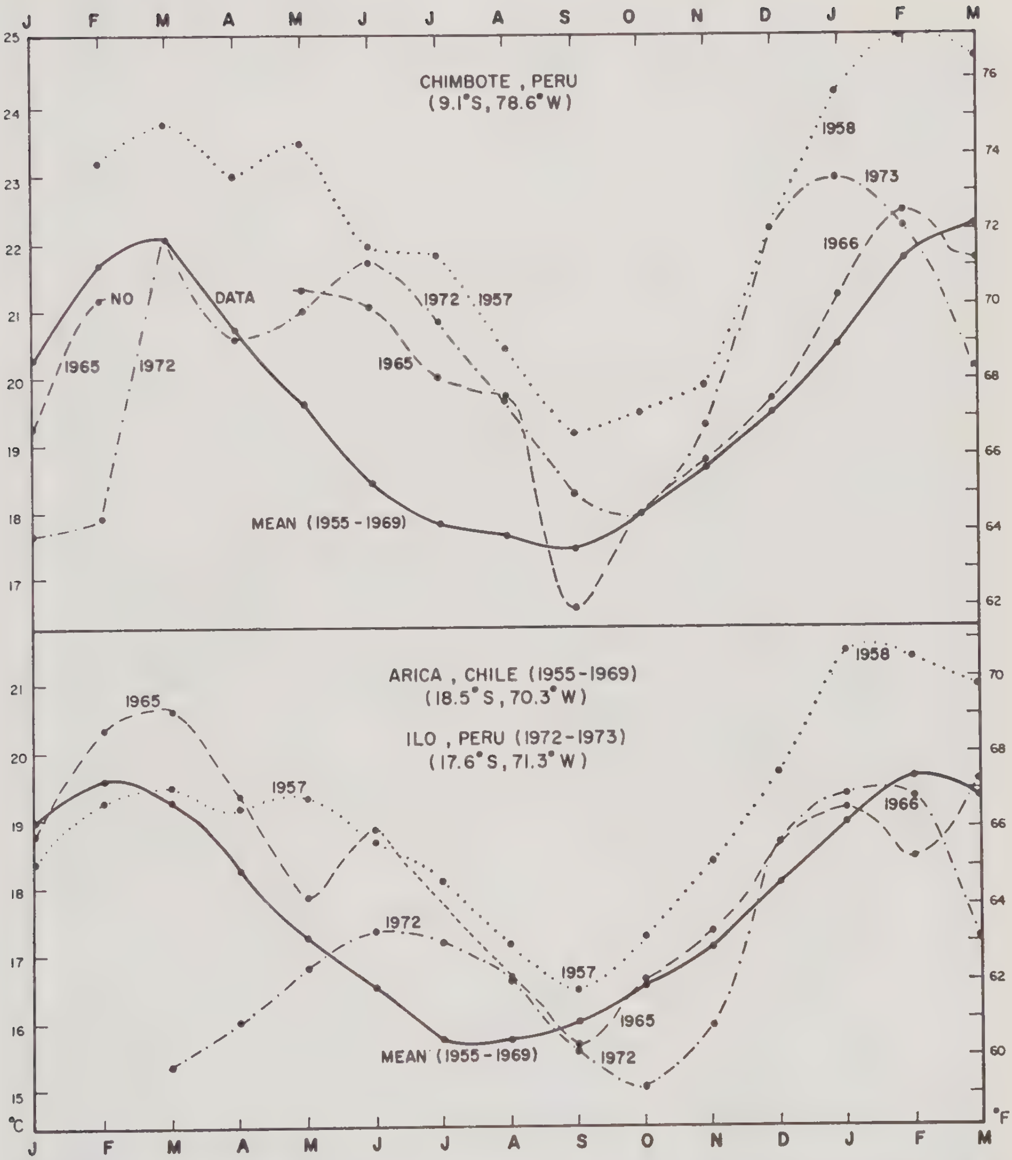

FIGURE 11. Annual variations in sea-surface temperatures for three recent El Niño years (1957-1958, 1965-1966, 1972-1973) and for long-term means at Chimbote, Peru, Arica, Chile, and Ilo, Peru. Arica data for 1972-1973 were not available.

FIGURA 11. Variaciones anuales en las temperaturas de la superficie del mar de tres años recientes del Niño (1957-1958, 1965-1966, 1972-1973) y para las medias a largo plazo de Chimbote, Perú, Arica, Chile e Ilo, Perú. No se pudieron obtener los datos de Arica de 1972-1973.

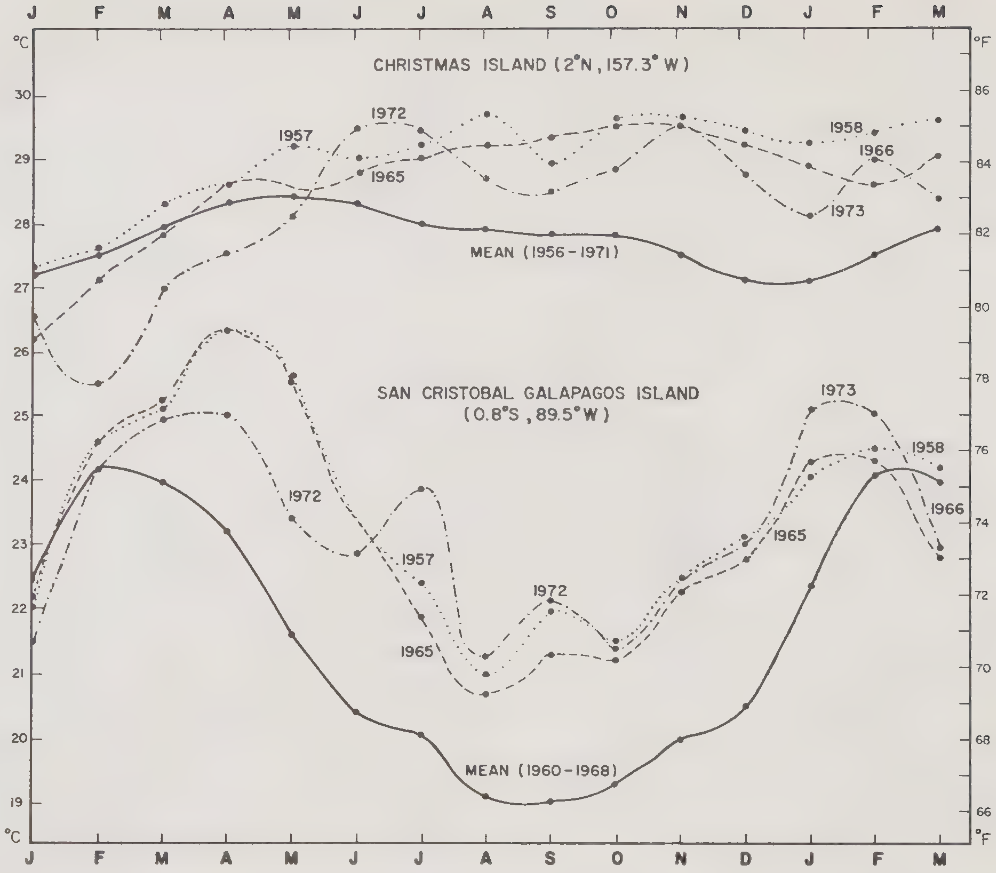

FIGURE 12. Annual variations in sea-surface temperatures for three recent El Niño years (1957-1958, 1965-1966, 1972-1973) and for long-term means for two equatorial islands in the eastern tropical Pacific.

FIGURA 12. Variaciones anuales en las temperaturas de la superficie del mar en tres años recientes del Niño (1957-1958, 1965-1966, 1972-1973) y para las medias a largo plazo de dos islas ecuatoriales en el Pacífico oriental tropical.

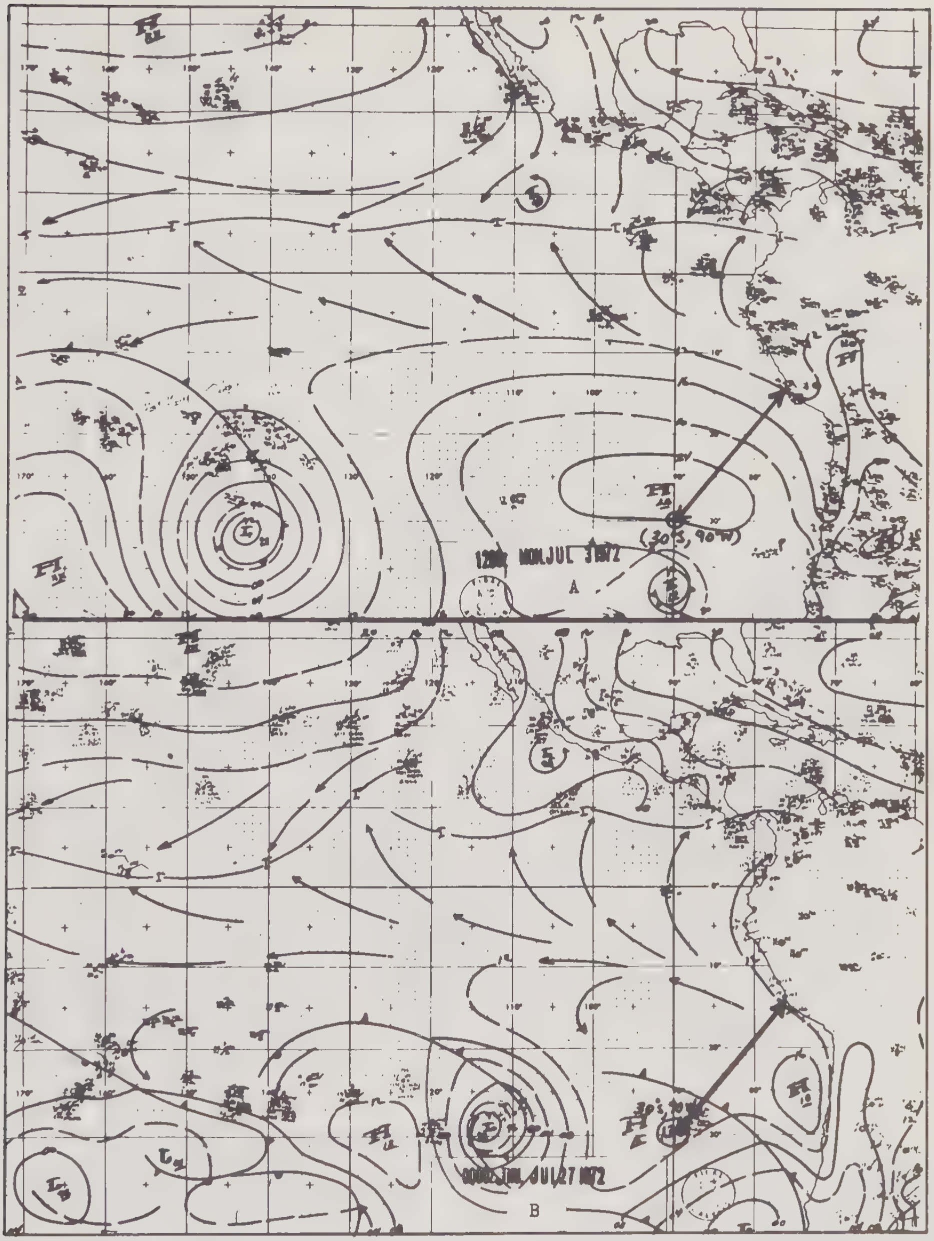

FIGURE 13. Sea-surface pressure and weather front analyses prepared by the National Weather Service, Washington, D. C., for July 3, 1972 (A) and July 27, 1972 (B). Heavy line from the coast of Peru (16°S) to 30°S-90°W indicates end points for obtaining data for pressure gradient index.

FIGURA 13. Análisis de la presión superficial del mar y del frente atmosférico, preparado por el National Weather Service, Washington, D. C., para el 3 de julio 1972 (A) y el 27 de julio 1972 (B). La línea gruesa desde la costa del Perú (16°S) a los 30°S-90°W indica los puntos finales de los que se obtuvieron datos para el índice del gradiente de presión.

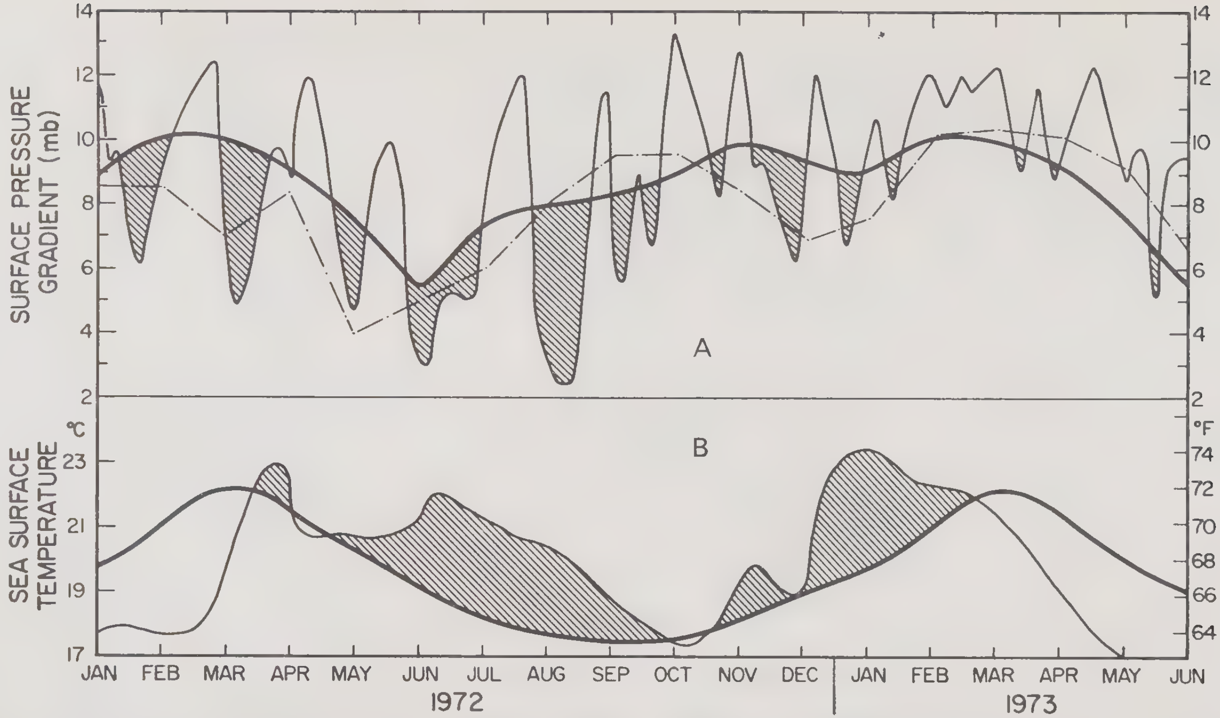

FIGURE 14. Annual variations in sea-surface pressure gradient between the coast of Peru (16°S) and 30°S-90°W (A). The heavy line represents the long-term mean pressure gradient, and the dot-dash line is the annual variation during the 1957-1958 El Niño based on monthly mean pressure gradients between the same points. Annual departures of sea-surface temperatures from the long-term means (smooth curve) at Chimbote, Peru are shown in (B). Hatched areas in (A) show periods of below-normal pressure gradients. Hatched areas in (B) show above-normal temperatures.

FIGURA 14. Variaciones anuales en el gradiente de presión de la superficie del mar entre la costa del Perú (16°S) y los 30°S-90°W (A). La linea gruesa representa la media a largo plazo del gradiente de presión, y la línea punto-guión es la variación anual durante el Niño de 1957-1958 basada en la media mensual de los gradientes de presión entre los mismos puntos. Las desviaciones anuales de las temperaturas superficiales del mar de las medias a largo plazo (curva suave) en Chimbote, Perú, se presenta en (B). Las áreas sombreadas a rayas en (A) indican períodos de gradientes de presión debajo de lo normal. Las áreas sombreadas a rayas en (B) indican temperaturas superiores a lo normal.

EL NIÑO DE 1972-1973 EN EL OCEANO PACIFICO ORIENTAL TROPICAL[1]

por

Forrest R. Miller[2] y R. Michael Laurs[3]

EXTRACTO

A comienzos de febrero de 1972, no se registró el enfriamiento común estacional del agua superficial del Océano Pacífico oriental en la región de la Corriente del Perú y a lo largo del ecuador. En julio las estaciones tropicales, costeras y de las islas ecuatoriales, y los barcos que cruzaban la linea ecuatorial registraron temperaturas superficiales del mar de 6° a 8°F (3.3°-4.4°C) más altas que la media a largo plazo. Las anomalías se esparcieron sobre la mayoría del Pacífico oriental tropical, y al oeste en el Pacífico central ecuatorial. En octubre, las temperaturas superficiales de las estaciones costaneras a lo largo de Sudamérica volvieron a la normalidad, pero en noviembre y diciembre de 1972, las temperaturas de nuevo ascendieron rápidamente con una anomalía de temperatura que alcanzó 8.1°F (4.2°C) sobre la media a largo plazo registrada en Puerto Chicama, Perú (7°42′S-79°27′W). Después de enero 1973 las temperaturas de la superficie del mar volvieron rápidamente a la normalidad en la mayoría del Pacífico oriental tropical y en marzo de 1973 el Niño había completado su ciclo.

Se discuten las anomalías mensuales de las temperaturas de la superficie del mar en el Pacífico oriental tropical para indicar la extensión y magnitud del calentamiento. Los perfiles anuales de temperatura en varias estaciones costeras y de las islas ecuatoriales sudamericanas se comparan con los perfiles de temperatura de los años en que ocurrió el Niño en 1957-1958 y 1965. Se comparan también las características de los perfiles de las anomalías de temperatura en Puerto Chicama durante varios años muy cálidos para el período de 1925-1972. Finalmente, se examinan los factores meteorológicos que contribuyen al debilitamiento de los vientos alisios del sudeste y a la reducción del afloramiento a lo largo de la costa sudamericana en 1972-1973.

INTRODUCCION

Periódicamente grandes secciones del Océano Pacífico oriental tropical y subtropical experimentan en los estratos superficiales un enfriamiento o calentamiento excesivo. Se cree que las anomalías en gran escala que perduran varios meses hasta más de un año, son manifestaciones de los procesos de la interacción aire-mar que ocurren en escala global. Las condiciones anómalamente cálidas del océano, denominadas comúnmente como el Niño, prevalecieron sobre la mayor parte del Pacífico oriental tropical durante 1972-1973.

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[1] Este estudio sumariza la investigación realizada como parte de un programa pesquero de información, patrocinado por el National Marine Fisheries Service, Southwest Fisheries Center, La Jolla, California. La participación en este estudio por la Comisión Interamericana del Atún Tropical fue hecha bajo los contractos del NOAA 03-4-208-59 y 03-5-208-83 con el National Marine Fisheries Service, La Jolla, California.

[2] Comisión Interamericana del Atún Tropical, La Jolla, California 92037.

[3] National Marine Fisheries Service, Southwest Fisheries Center, La Jolla, California 92037.

Los objetivos de este estudio son: (1) describir el grado y magnitud del calentamiento asociado con el Niño de 1972-1973, mediante el examen de las pautas mensuales de las anomalías de la temperatura de la superficie del mar en el Pacífico oriental tropical; (2) comparar las condiciones termales del océano durante el Niño de 1972-1973 con las de otros períodos del Niño; y (3) examinar los factores meteorológicos superficiales que contribuyeron al debilitamiento de los vientos alisios del sudeste y a la reducción en el afloramiento a lo largo de la costa sudamericana en 1972-1973.

FUENTE DE DATOS Y METODOS

El National Marine Fisheries Service (NMFS), Southwest Fisheries Center, La Jolla Laboratory, como parte de su programa de investigación oceanográfico pesquero, realizado para predecir las condiciones de pesca, ha desde 1960 vigilado la temperatura del océano en el Pacífico oriental entre los 30°S y 60°N. La mayoría de los datos empleados en este estudio fueron obtenidos como parte de este programa de reconocimiento.

La mayor fuente de datos usada en la preparación de los diagramas de las temperaturas superficiales del mar (Figura 1) y las anomalías de las medias a largo plazo (Figuras 2-9) son los informes meteorológicos marinos recibidos de barcos en el mar. Estos informes se reciben por medio de transmisiones sinópticas programadas, de embarcaciones mercantes, pesqueras y de investigación de los E. U. y extranjeras de acuerdo a los procedimientos establecidos por la Organización Mundial Meteorológica. Cerca de 4,000 informes meteorológicos sinópticos marinos, incluyendo observaciones de la temperatura de la superficie del mar (TSM), de las regiones del Océano Pacífico oriental tropical y subtropical se procesan cada mes en el laboratorio del NMFS en La Jolla. Una descripción de como se reciben y se procesan las observaciones fue presentada en una publicación por Johnson, Flittner y Cline (1965). Aunque se han cambiado algunos de los detalles específicos del programa, los métodos actuales de procesamiento son esencialmente los mismos a los descritos en esa publicación. Cada mes se promedian los datos de la TSM por cuadrángulos de 1 grado y se grafican en la computadora. Los gráficos de las isotermas se hacen mediante el análisis manual.

A causa de que los datos de la TSM se obtienen principalmente de observaciones realizadas por embarcaciones mercantes y pesqueras, la distribución espacial y temporal de los datos se concentra a lo largo de las líneas de navegación y en las zonas pesqueras en el Océano Pacífico oriental tropical. Los datos de la TSM basados en una media de 20 años (1948-1967) se emplean para proporcionar datos fundamentales en regiones en que éstos son escasos. Estos datos fueron computados según las observaciones superficiales del mar suministradas por el National Climatic Center, Asheville, North Carolina, gracias a la colaboración del laboratorio del NMFS, La Jolla, California, del Pacific Environmental Group, NMFS, Monterey, California y del Fleet Numerical Weather Central, U. S. Navy, Monterey, California. Estos datos a largo plazo se usan además para preparar los gráficos mensuales de las anomalías de temperatura de la superficie del mar. Las pautas anómalas se obtienen al substraer los datos de la TSM de la media a largo plazo de los meses correspondientes.

Este estudio no incluye los análisis de la TSM de cada mes del Niño de 1972-1973. Sin embargo, los análisis de diciembre 1971 y diciembre de 1972, representantes de los años de "frío" y "calor", respectivamente, se presentan en la Figura 1. Las diferencias principales en la distribución de la TSM en estos meses de diciembre de "frío" y "calor" se encuentran más acentuadas a lo largo de la costa sudamericana y en la zona ecuatorial. Por ejemplo, la media mensual de las TSM en las estaciones del litoral a lo largo de la costa sudamericana, fluctuaron de unos 59° a 61°F (15.0°-16.1°C) en diciembre de 1971 y de 63° a 72°F (17.2°-22.2°C) en diciembre de 1972. Además, en 1971 hubo un fuerte gradiente termal en una estrecha faja de 200 a 250 km de amplitud, paralela al litoral peruano y extendiéndose a unos 2°S, donde viró abruptamente al este para intersecar la línea de la costa. La porción meridional del gradiente fue más difusa y no tan bien definida como la del norte. En 1972, en contraste, el gradiente termal fue más débil y se localizó más hacia el sur (en su mayoría al sur de los 10°S) que en 1971. Además el extremo meridional del gradiente se definió mejor en 1972 que en 1971. Por lo consiguiente el área ocupada por aguas con una temperatura superficial de más de 80°F (26.7°C) en el Océano Pacífico oriental tropical fue considerablemente superior en diciembre de 1972 que en diciembre de 1971.

Los análisis de la TSM de otros meses fueron obtenidos de Laurs (1972-1973). Para graficar la Figura 10 se emplearon las temperaturas superficiales medidas con termómetros de cubo en estaciones costeras entre los 5°S y los 20°S suministradas por el Living Marine Resources, Inc. (LMR), San Diego, California.

A principios de 1972, a medida que las temperaturas del mar empezaron a ascender, se trató de observar la fuerza general de los vientos alisios del sudeste, frente a la costa sudamericana, con relación al calentamiento de la superficie de la Corriente del Perú. Como los informes de los vientos en la superficie fueron muy escasos a lo largo de la costa, se usaron dos veces al día los gráficos de la presión superficial. Según estos gráficos, provistos por el National Weather Service, Washington, D. C., se preparó un índice del gradiente de presión. El gradiente fue obtenido según los diagramas diarios, al substraer la presión superficial de una estación costera del Perú cerca a los 16°S y un punto a los 30°S-90°W (aproximadamente el centro de alta presión del Pacífico sudeste). Los promedios semanales del gradiente de presión fueron graficados contra la media a largo plazo del gradiente de presión entre las mismas localidades.

INFORMACION GENERAL SOBRE EL NIÑO

Para los pescadores y pobladores costeros de la América Central y Sudamérica, especialmente Ecuador y Perú, el Niño significa aguas costeras inusitadamente cálidas, marea roja, pesca pobre y frecuentemente lluvias torrenciales culminado todo comúnmente en diciembre. Aunque el Niño es un término familiar con una connotación religiosa (el Niño se refiere el Niño Dios, nombre que fue escogido ya que la culminación de este fenómeno ocurre cerca a la fecha tradicional de navidad), aparentemente no se conoce el significado original. Otros nombres dados a este fenómeno oceanográfico-meteorológico son: *El Pintor* o *Pintor de Callao* que se refiere al ennegrecimiento del casco de los barcos y de las casas causado por el hidrógeno sulfurado producido por la descomposición de organismos marinos (Wooster, 1960); *Aguaje* que significa probablemente inundación por las lluvias y marea roja que comúnmente ocurre simultáneamente a lo largo del Perú y Ecuador de diciembre a febrero durante los años del Niño (A. Alvariño, La Jolla, Calif., com. pers.); y la *Corriente del Niño* identificada por los navegantes como una corriente que se mueve al sur apareciendo a fines del año en contraste a la Corriente del Perú que se mueve normalmente al norte (James, 1953; Hawken, 1973).

En los años en que aparece el Niño muy débilmente o no aparece, la Corriente fría del Perú perpetúa una corriente fría hacia el norte bajo estratocúmulos muy bajos, un clima de desierto se extiende desde Chile hasta el sur del Ecuador, y las lluvias tropicales se encuentran confinadas a la zona ecuatorial al norte de los 5°S. En contraste, los años del Niño se relacionan con un cambio principal en los sistemas de la presión atmosférica extendiéndose desde Sudamérica hasta por lo menos la región central del Pacífico sur. Comenzando en el invierno austral de un año, el gran intercambio de calor de las aguas cálidas costeras provoca lluvias casi tropicales e inundaciones frecuentes a lo largo de las llanuras costeras. Esta condición amaina algo durante la primavera austral; pero cuando la presión atmosférica costera permanece baja, siguen fuertes lluvias y vientos alisios del sudeste débiles, y ocurre otro máximo en la temperatura del mar en la Corriente del Perú durante el verano siguiente. Cuando el calentamiento del Niño se aproxima a su máximo, la pesca costera de la anchoveta, *Engraulis ringens*, se vuelve más errática, mermando las capturas, mientras las especies tropicales son más abundantes e invaden las aguas costeras a veces hasta el sur del Perú (Wooster, 1960).

En los últimos 50 años, los registros de las temperaturas superficiales del mar revelan que las condiciones del Niño prevalecieron a lo largo de la costa sudamericana en 1925, 1930, 1939, 1941, 1943, 1951, 1957, 1965, 1969 y 1972. Existe una indicación, que ha habido un ciclo de 15 a 16 años en las mayores anomalías positivas de la TSM que ha ocurrido en las estaciones costeras de Perú y Ecuador durante los períodos del Niño en 1925, 1941, 1957 (Berlage, 1966; Quinn y Burt, 1970), y más recientemente en 1972. Stevenson, *et al.* (1970) observó además que los escritos indicaban máximos en las condiciones del Niño a los 6 y 16.5 años en las estaciones costeras de Perú y Ecuador.

Las publicaciones referentes a los Niños ocurridos antes del decenio de 1950, son principalmente descriptivas y contienen generalmente referencias de la Corriente cálida del Perú (Murphy, 1926; Schott, 1931; Gunther, 1936). Aparentemente, la evidencia con respecto a los efectos del calentamiento en las propiedades físicas de la Corriente del Perú o los efectos en la flora y fauna allí, se limitó a las áreas costeras adyacentes.

HIPOTESIS SOBRE EL ORIGEN DEL NIÑO

La investigación sobre los fenómenos del Niño ocurridos anteriormente, indica tres hipótesis generales sobre el origen del agua relativamente cálida y de baja salinidad que invade periódicamente o se encuentra en la superficie de la Corriente del Perú frente a Sudamérica durante los años del Niño. Currie (1953) y Bjerknes (1966) sugirieron que fuertes vientos norteños soplan hacia el sur en el Golfo de Panamá y al este de las islas Galápagos, y que la zona de convergencia intertropical se desplaza al hemisferio austral. Esto conduce a una advección al sur del agua cálida ecuatorial de baja salinidad y a una desintegración del frente ecuatorial oceánico frente al Ecuador cuando los vientos alisios del sudeste se vuelven débiles frente a la costa sudamericana. Schott (1931) y James (1953) supusieron que existía una advección al este, del agua cálida que se encuentra siempre al sur de las islas Galápagos y al oeste de la Corriente del Perú. Existe alguna evidencia de acuerdo a M. Tsuchiya (Scripps Institution of Oceanography, La Jolla, Calif., com. pers.) que indica que el agua de la superficie puede desplazarse hacia el este entre los 5°S y 10°S y al este de los 110°W, en donde la Contracorriente Ecuatorial del Sur puede a veces ascender a la superficie cuando los vientos alisios del sudeste disminuyen en los años del Niño. Stevenson *et al.* (1970) observó que en dos ocasiones (abril-junio y octubre-diciembre 1965) el agua cálida superficial de alta salinidad penetró hasta 80 millas de la costa entre los 8°S-10°S. Indicaron que esta corriente al este se encontraba asociada con la Contracorriente Ecuatorial del Sur y que esta corriente puede haber transportado aguas cálidas hasta muy cerca de la costa durante los períodos del Niño. De acuerdo a Sears (1954) y Wooster (1960), cuando los vientos alisios del sudeste se debilitan y el afloramiento o mezcla vertical llega a ser mínimo en la Corriente del Perú y su extensión ecuatorial, ocurre un calentamiento *in situ* en la Corriente del Perú a causa de que hay menos nubosidad estratiforme. Además, la insolación está a su máximo durante el verano del hemisferio austral cuando las condiciones del Niño son más intensas. Se conoce que caen cantidades más grandes de lluvia de nubes convectivas sobre el Ecuador y Perú y en regiones de la Corriente del Perú adyacentes al océano en años cálidos (Bjerknes, 1961). Cantidades más grandes de humedad son transportadas en la atmósfera y caen en forma de fuertes lluvias. Esto en parte, puede ser la causa de las áreas de aguas superficiales de salinidad más baja que se encuentran a lo largo de la costa durante un fenómeno del Niño.

Una discusión sobre las propiedades de la superficie y subsuperficie de la Corriente del Perú durante el Niño de 1965-1966 es presentada por Stevenson *et al.* (1970). Presentan además un examen de la literatura referente al posible origen del agua cálida que se encuentra a lo largo de la costa sudamericana durante los años del Niño.

Wooster (1960) calculó que, "Durante los años del Niño, existe un debilitamiento general de la circulación atmosférica en el estrato marino, y que la reducción en el componente del viento paralelo a la costa es responsable por un debilitamiento o cesación del afloramiento". Concluye que el Niño es un término genérico con una aplicación no solamente a la costa peruana pero a las áreas costeras occidentales de California, el sudeste del Africa, Australia occidental y Vietnam.

Bjerknes (1966) al discutir las ramificaciones del tiempo del Niño de 1957-1958 afirmó que, "El Niño es un fenómeno veranero del hemisferio austral y que la alta temperatura del mar medida en esta época es una derivación del máximo de insolación anual, especialmente en la banda de los alisios donde se encuentran pocas nubes . . . El debilitamiento de los alisios tiene efectos más repentinos y espectaculares en el océano en términos de la temperatura producida por la cesación del afloramiento . . . Siempre que un área de agua aflorada es cubierta por una invasión de agua cálida superficial, la atmósfera se encuentra expuesta a una nueva fuente de calor originando un intercambio de la convección vertical y lluvia".

La presencia de grandes charcos de agua cálida entre los 5°S y 10°S durante el verano austral fue indicada por Wyrtki (1964). Observó que los análisis y datos detallados revelaban la existencia de una lengua cálida de agua al oeste y adyacente a la Corriente fría del Perú. Wyrtki afirmó que estas áreas aisladas de altas temperaturas no podían ser causadas por advección, y que el calentamiento local era importante ya que comúnmente el agua más fría rodea los parches de agua cálida durante los años en los que no ocurre el fenómeno del Niño. Los análisis de la temperatura de la superficie del mar presentados por Laurs (1972-1973) indican que las áreas de aguas cálidas descritas por Wyrtki se extendieron al este hasta la costa del Ecuador en la primavera y el verano austral de 1972. Durante los años fríos, las áreas de aguas cálidas permanecen por lo común 400 a 500 km frente a la costa. Wooster y Guillén (1974) observaron también la lengua de agua cálida durante el Niño de 1972-1973.

Berlage (1966) sugirió que el debilitamiento de la Corriente del Perú se relaciona a la "Oscilación Austral", donde la presión atmósferica en el centro de alta presión de la región sudeste del Pacífico se reduce y la presión llega a ser relatimente alta sobre Indonesia. En este caso se desacelera la circulación general atmosférica e hidrosférica a través de la parte meridional del Océano Pacífico. Por lo consiguiente, la Corriente del Perú se vuelve débil, y el agua relativamente cálida a lo largo de la costa peruana penetra en la Corriente Ecuatorial del Sur. Berlage explica además que las altas presiones en la parte este del Pacífico Sur y las presiones bajas en Indonesia producen una aceleración en la "Oscilación Austral". En este caso, la Corriente del Perú y los vientos alisios del sudeste son más fuertes y se reducen las temperaturas superficiales del mar. Quinn y Burt (1970) concluyeron además que el Niño se relacióna a las anomalías oceánicas y atmosféricas de gran escala, asociadas con la Oscilación Austral que produce interacciones interhemisféricas inusitadas en el Pacífico ecuatorial. Los períodos anormales de grandes cantidades de lluvia sobre la zona seca ecuatorial al oeste de 140°W, se han asociado a las condiciones del Niño que empezaron anteriormente en el año al este de las islas Galápagos de acuerdo a Quinn y Burt (1970, 1972).

CONDICIONES DE LA TEMPERATURA OCEANICA DURANTE EL NIÑO DE 1972-1973

Las condiciones de la temperatura superficial del mar en la mayor parte del Pacífico oriental tropical durante febrero de 1972 a abril de 1973, siguieron un patrón en el que (1) hubo un calentamiento rápido de temperatura por debajo de lo normal a más allá de lo normal, seguido (2) por un ligero cambio a temperaturas casi normales, (3) luego un segundo período de calentamiento rápido en el que las temperaturas alcanzaron un nivel mucho más alto que lo normal que persistió varios meses, y finalmente (4) un regreso rápido a las temperaturas normales o más frías que lo normal. En general, los cambios en las pautas de la temperatura de la superficie del mar fueron más complejos a lo largo de la costa sudamericana y al oeste de las islas Galápagos de lo que fueron más lejos fuera de la costa. Además, los índices de los cambios de temperatura y su desviación de lo normal fueron frecuentemente mayores a lo largo de la costa de lo que fueron en las aguas ecuatoriales fuera de la costa. Las desviaciones de la media a largo plazo de las temperaturas superficiales del mar en el Pacífico oriental tropical en enero de 1972 a abril de 1973 se presentan en las Figuras 2 a 9.

Período inicial de calentamiento

Las temperaturas más frías que lo normal persistieron generalmente sobre la mayoría del Pacífico oriental tropical desde fines de 1969 a enero de 1972 (gráfico de anomalías de enero 1972 presentado en la Figura 2a). En febrero de 1972, cuando las temperaturas del agua de 100 a 300 millas al sudeste de las islas Galápagos aumentaron más de 6°F (3.3°C) que las del mes anterior, se indicó un cambio a condiciones de temperaturas más cálidas en el océano, que condujeron luego al Niño de 1972-1973 (Figura 2b). El calentamiento debilitó también las condiciones de temperatura por debajo de lo normal que habían persistido durante varios meses a lo largo de la zona ecuatorial al oeste hasta los 145°W. El calentamiento continuó y fue más prominente en marzo de 1972 (Figura 3a) cuando las anomalías positivas de temperatura aparecieron en la mayoría de la zona ecuatorial desde la costa sudamericana hasta los 145°W. Las desviaciones negativas de la media a largo plazo persistió al oeste de esta longitud, pero con magnitudes reducidas. Las temperaturas en las áreas frente a Guayaquil, Ecuador, y a lo largo del ecuador desde los 120°W a 140°W fueron 6°F (3.3°C) más altas en marzo de 1972 que en marzo de 1971.

La tendencia de calentamiento que ocurrió en febrero y marzo de 1972 parece estar relacionada a vientos más suaves de lo normal que redujeron el afloramiento, y a una cubierta de nubes inferior a lo normal, y a un aumento de la radiación solar. Estas condiciones atmosféricas se asociaron con un cambio al sudoeste del centro de alta presión del hemisferio austral y a un cambio al sur de los 5° de latitud, de la convergencia intertropical.

Regreso a la normalidad

Las temperaturas más altas que lo normal continuaron durante abril de 1972 (Figura 3b) entre Sudamérica y las islas Galápagos desde los 5°N a 10°S y se extendieron al norte penetrando el Golfo de Panamá. Sin embargo, no ocurrió una intensificación significativa en la condición de calentamiento; en realidad, las temperaturas cercanas al litoral a lo largo de la costa ecuatoriana volvieron casi a la normalidad. Durante mayo (Figura 4a), las temperaturas de la superficie del mar a lo largo de una estrecha faja de la costa sudamericana desde el ecuador a los 10°S volvió casi a lo normal. Más lejos fuera de la costa aproximadamente desde los 80°W a 88°W las temperaturas permanecieron superiores a lo normal, pero la magnitud de la desviación y duración no fue tan grande como durante el mes anterior. Las temperaturas entre los 5°N y 5°S desde las islas Galápagos hasta los 120°W fueron tan altas como 4°F (2.2°C) más de lo normal.

La reducción de las temperaturas superficiales del mar a lo largo de la costa sudamericana durante abril y mayo de 1972 se relacionó al restablecimiento parcial del centro de alta presión subtropical frente a Sudamérica y al desarrollo consiguiente de los vientos sudestes a lo largo de la costa que aparentemente produjeron el afloramiento costero. Fuera de la costa los vientos alisios del sudeste permanecieron débiles y el calentamiento a lo largo de la región ecuatorial pareció relacionarse al debilitamiento del afloramiento que comúnmente ocurre allí.

Un segundo período de calentamiento

Un segundo período de calentamiento rápido comenzó en junio de 1972 (Figura 4b). Ocurrió un calentamiento pronunciado fuera a lo largo de la costa sudamericana hasta los 120°W, excepto por una pequeña área frente al Ecuador. Entre los 80°W y 90°W las temperaturas ascendieron tanto como 6°F (3.3°C) sobre lo normal. Fue evidente también un calentamiento extenso en el área al oeste de los 140°W entre los 5°W y 5°N, y una extensión al norte hasta las islas hawaianas, entre los 160°W y 175°W. Durante julio de 1972 (Figura 5a) hubo un incremento pronunciado en el área e intensidad de las temperaturas anómalamente cálidas del océano. Estas condiciones prevalecieron a lo largo de la costa sudamericana, excepto por un área muy pequeña frente a Lima, Perú, debajo de los 10°S al norte penetrando el Golfo de Panamá y en una banda continua a lo largo de la línea ecuatorial hasta los 180°W (y probablemente más allá). La magnitud de las desviaciones positivas excedieron 8°F (4.4°C) en varias áreas a lo largo del ecuador desde los 100°W hasta la costa sudamericana.

Las condiciones del Niño continuaron durante los meses de la primavera austal y hasta enero de 1973, apareciendo generalmente aguas anómalamente cálidas a lo largo de la costa sudamericana y extendiéndose en una banda entre los 10°S y 10°N al oeste hasta los 170°W (Figuras 5b-8b). Entre la costa y los 90°W las anomalías positivas fluctuaron de 2° a 8°F (1.1°-4.4°C) con valores de 4° a 6°F (2.2°-3.3°C) predominando durante la mayoría de los meses. Hubo también períodos en los que en ciertas regiones costeras las temperaturas medias mensuales volvieron a la normalidad, por ejemplo frente al norte del Perú y Ecuador en octubre de 1972 (Figure 6b), y frente a la parte central del Perú en noviembre de ese mismo año (Figura 7a). En aguas a lo largo de la zona ecuatorial entre los 10°S y 10°N y al oeste de los 90°W las anomalías positivas de temperatura fluctuaron de 2° a 8°F (1.1°-4.4°C) predominando los valores de unos 4°F (2.2°C). Hubo una expansión al norte de la anomalía del agua cálida extendiéndose sobre la mayoría del Pacífico oriental tropical desde octubre a diciembre 1972 (Figuras 6b y 7b) con desviaciones positivas de 2° a 4°F (1.1°-2.2°C) observadas frente a la costa de México. La magnitud de la anomalía durante septiembre 1972 (Figura 6a) fue algo inferior que durante los meses anteriores y los que siguieron. Esto parece relacionarse al restablecimiento parcial de los vientos alisios del sudeste que causaron afloramiento y procesos de interacción aire-mar que enfriaron ligeramente las aguas oceánicas.

Conclusión de las condiciones del Niño

Durante febrero de 1973 (Figura 8b) la extensión y magnitud de la anomalía positiva de temperatura se redujo marcadamente de lo que había sido durante los dos o tres meses anteriores, y fue aparente que el Niño estaba por concluir. Las temperaturas del agua en una faja estrecha a lo largo de la costa sudamericana, excepto por una pequeña área frente al norte de Perú y Ecuador, volvió a ser normal o ligeramente debajo de lo normal. Además la banda de agua anómalamente cálida que se había extendido durante varios meses a lo largo del ecuador desapareció entre los 120°W y 145°W. La magnitud de la anomalía había disminuído en su mayor parte hasta unos 2°F (1.1°C) sobre lo normal, solo con unas pequeñas áreas que alcanzaron 4°F (2.2°C) más de lo normal. En marzo de 1973 (Figura 9a) permanecían solo pequeños parches esparcidos de agua anómalamente cálida. El Niño finalizó en abril de 1973 (Figura 9b) cuando las condiciones de temperatura normales o debajo de lo normal fueron evidentes a lo largo de la mayoría de la costa sudamericana y fuera de la costa en la zona ecuatorial.

ANALOGIAS EN LA TEMPERATURA OCEANICA DURANTE FENOMENOS RECIENTES DEL NIÑO

Aunque la intensidad, duración y áreas de influencia máxima indican alguna variación, los datos de la TSM de las estaciones del litoral y de las islas indican que las tendencias de las pautas anómalas de la temperatura oceánica han sido similares durante períodos en los que las condiciones del Niño han sido bien desarrolladas.

La Figura 10 es una sección cronológica de las anomalías de la TSM, basada en datos de Puerto Chicama, Perú, desde enero de 1925 a enero de 1969, obtenida del LMR. Después de enero 1969, se emplearon los datos de Chimbote, Perú y se ajustaron estadísticamente para Puerto Chicama. Se considera que estos datos representan las condiciones de temperatura de la superficie del mar a lo largo de la costa del Ecuador y Perú. En la Figura 10, los datos han sido realineados para indicar analogías en las pautas de anomalías durante los años más pronunciados del Niño; por lo consiguiente se encuentran interrupciones o repeticiones en los datos en algunos años. Varias características son evidentes en la Figura 10. En la mayoría de los casos, excepto 1930 y desde 1939 a 1941, la primavera y el verano austral antes del Niño fueron mucho más fríos que lo común, con las aguas costeras frente al Perú significativamente por debajo de la media a largo plazo durante períodos de más de 12 meses. Además, las anomalías positivas de los años fuertes del Niño de 1925, 1941, 1957, 1965 y 1972 fueron todas bimodales. Ocurrió un ápice anómalo en el otoño o a principios del invierno y otro a fines del año o a principios del siguiente. En los años más débiles del Niño de 1930, 1943, 1951, 1953 y 1969, uno de los ápices anómalos, comúnmente el que aparece en el verano austral (diciembre-enero), fue ya sea reducido o ausente. En septiembre u octubre tanto en años débiles como fuertes del Niño, la anomalía positiva alcanzó un valor mínimo. Esto ocurre en la primavera austral cuando la temperatura superficial del mar es mínima en la Corriente del Perú. Durante el máximo del Niño de 1972-1973, las anomalías positivas en Puerto Chicama (Chimbote) aparecieron en mayo de 1972, 5.8°F (3.2°C) y diciembre de 1973, 8.3°F (4.6°C), y la anomalía mínima positiva apareció en octubre de 1972, 2.0°F (1.1°C).

Los ápices bimodales de las anomalías positivas de la TSM que son similares en 1957, 1965 y 1972 se retratan gráficamente en la Figura 10. Debido a la analogía aparente entre estos tres años cálidos, es apropiado examinar más detalladamente los perfiles estacionales de la TSM de otras estaciones ecuatoriales y costeras sudamericanas, de lo que se indica en la Figura 10. Además, en los siguientes párrafos se examinan las divergencias de cada perfil anual de temperatura según la media a largo plazo.

Las Figuras 11 y 12 presentan los cambios estacionales de las temperaturas superficiales del mar y sus divergencias según la media a largo plazo de 1957-1958, 1965-1966 y 1972-1973 de dos estaciones costeras sudamericanas y dos estaciones isleñas ecuatoriales. La media de las curvas estacionales ha sido elaborada según los datos publicados por el National Ocean Survey (NOS) de las islas del Pacífico y de las estaciones costeras (Jones, 1970). Los datos de 1957 y 1965 de Chimbote, Perú (9°S), Arica, Chile (18°S), Isla Christmas (2°N-157°W) y San Cristobal, islas Galápagos (2°S-90°W), fueron obtenidos de una publicación del NOS. Durante 1972, los datos de la TSM de Chimbote e Ilo, Perú (Ilo está situada cerca a Arica, Chile, y no se tienen datos de la TSM en 1972) fueron suministrados por LMR. Como los datos de la TSM de dos estaciones isleñas ecuatoriales (Figura 12) no estaban completos en 1972, se determinaron las estimaciones de los valóres mensuales de la TSM, basados en las medias a largo plazo y las anomalías de cada lugar según los análisis mensuales publicados por Laurs (1972).

Es evidente según la Figura 11 que las TSM en 1957-1958 permanecieron muy por encima de la media correspondiente a todo el período en Chimbote y sobre la media después de febrero en Ilo. Durante 1965, los perfiles de la TSM fueron similares a los de 1957. En 1972 los valores de la TSM en cada estación permanecieron inferiores o próximos a la media de largo plazo hasta abril o mayo. Luego, continuaron superiores a la media de largo plazo hasta octubre, cuando la TSM se redujo con respecto a la media de largo plazo en Chimbote e Ilo. A medida que se aproximaba el verano austral (octubre), las TSM al norte de los 10°S aumentaron más rápido que la media a largo plazo y alcanzaron un ápice en enero de 1973. Se calcula que la desviación más grande de la media a largo plazo se presentó a lo largo de la costa al sur de Guayaquil (5°S), donde la anomalía fue de unos + 9°F (5°C) en enero de 1973.

En la Figura 12, es evidente una variación pequeña anual de la TSM en la Isla Christmas y una grande en San Cristobal (islas Galápagos). En todos los tres años del Niño, las curvas de la TSM fueron superiores a la media en el área de las Galápagos en febrero y no volvieron a la media hasta después de febrero del año siguiente. En el área de las islas Galápagos, las desviaciones de 1972 y 1965 de la media fueron muy similares a las de 1957-1958. En la Isla Christmas, las desviaciones significativas de las TSM según la media aparecieron después de junio. Quinn y Burt (1970) pusieron de relieve la demora en el calentamiento en la Isla Christmas.

INFLUENCIA ATMOSFERICA DEL NIÑO EN 1972

Durante los períodos del Niño existen debilitamientos o reducciones en la velocidad de los vientos alisios del sudeste frente a Sudamérica, especialmente al sur de los 15°S, que resultan en una disminución de la fuerza del viento en la superficie, necesaria para mantener la mezcla vertical y el afloramiento en la Corriente del Perú relativamente débil. Este fenómeno se relaciona a los cambios en gran escala de la circulación atmosférica por medio de los cuales el centro subtropical de alta presión cerca a los 30°S-90°W, se desplaza frecuentemente por las tormentas que ocurren más cerca del ecuador en los años del Niño. Cerca al litoral las variaciones en las configuraciones de la línea costera combinadas con gradientes termales, locales, tierra-mar, pueden crear condiciones más o menos favorables para la fuerza local del viento y la mezcla vertical del océano. En los años más cálidos, los gradientes termales costeras y los vientos locales se debilitan en un régimen ya retardado de los vientos alisios del sudeste. La mezcla vertical en la Corriente del Perú se reduce marcadamente y las capas superficiales no se enfrían ya efectivamente a causa del agua fría profunda.

Como la circulación atmosférica en el Pacífico del sur juega un papel importante en mantener y disminuir el afloramiento (inducido por el viento) en la Corriente del Perú, se examinaron las variaciones en el gradiente de presión de la superficie del mar entre los 30°S-90°W, cerca al centro climatológico del centro de alta presión del Pacífico sudeste y una estación en la costa del Perú a los 16°S. Las anomalías en el gradiente de presión suministraron un índice semanal de la fuerza general de los vientos alisios del sudeste por encima de una porción de la Corriente del Perú. Los datos de presión fueron obtenidos de gráficos globales de la presión superficial, preparados dos veces al día por el National Weather Service (NWS), Washington, D. C.

Durante el Niño de 1972-1973, prevalecieron dos pautas principales de la presión superficial sobre la parte oriental del Pacífico sur. Durante períodos de 7 a 14 días, los vientos alisios del sudeste fueron relativamente constantes y fuertes. La Figura 13a presenta un análisis de la presión superficial preparado por el NWS, en el que el centro de alta presión de la región sudeste del Pacífico subtropical fue la característica dominante frente a la costa sudamericana a mediados de julio de 1972. Las pautas de presión de este tipo produjeron gradientes de presión típicos de aquellos períodos cuando los vientos alisios del sudeste al sur de los 15°S fueron lo suficientemente fuertes para inducir una mezcla vertical y mantener el afloramiento en la Corriente del Perú. En contraste, hubo períodos frecuentes de 15 a 20 días en 1972-1973, cuando los centros de baja presión y los frentes atmosféricos se desplazaron hacia la costa entre los 20°S y 30°S. Un ejemplo de esta situación se indica en la Figura 13b. El pasaje sucesivo de áreas de baja presión, al este, pasando los 30°S-90°W causó un desvanecimiento del centro subtropical de alta presión sobre la región sudeste del Pacífico y los vientos alisios del sudeste se redujeron marcadamente. Durante los años fríos o en los que no apareció el Niño, los frentes atmosféricos y los centros de baja presión viraron comúnmente hacia el polo cerca a los 30°S y al oeste de los 100°W, y el centro sudeste de alta presión permaneció intenso. Wooster y Guillén (1974) indicaron que en Lima, Perú y en cualquier otro lugar a lo largo de la costa, las presiones superficiales fueron más bajas que lo normal en 1972, lo cuál estuvo de acuerdo con el desplazamiento al sur de la zona de convergencia intertropical durante los períodos del Niño. Parece que los sistemas meteorológicos en 1972 tuvieron más trayectorias hacia el ecuador debido probablemente a que las corrientes principales que gobiernan la troposfera o corrientes de chorro (jet streams) sobre el hemisferio austral no se encontraron en su posición usual la mayor parte del año. Recientemente, Krueger y Winston (1974) examinaron las anomalías en el flujo de la corriente ecuatorial de la troposfera sobre el Pácifico oriental. Indicaron que los vientos ecuatoriales de levante eran comúnmente débiles desde la superficie hasta los 700 mb (aproximadamente 3.5 km), y los vientos alisios del sudeste se reducían al sur de los 20°S frente a la costa sudamericana en asociación con un aumento (anómalo) del flujo de corriente ciclónica al oeste de los 90°W al nivel de 700 mb. Namias (1972) indicó que basado en datos de 20 años (1947-1966) en el Pacífico norte, las anomalías de los niveles a 700 mb y de la TSM tienen altas correlaciones negativas, y que existen teleconexiones similares sobre el Pacífico entre las temperaturas de la superficie del mar y los niveles a 700 mb.

La Figura 14a indica que ocurrieron frecuentemente períodos alternativos superiores a lo normal y debajo de lo normal de los gradientes de presión, frente a la costa sudamericana comenzando en enero de 1972. Aparentemente la gran reducción en la presión entre los 30°S-90°W y la costa del norte de Chile y la región central del Perú durante abril, marzo, junio, agosto y noviembre de 1972, causó suficiente debilitamiento en los vientos alisios del sudeste para mantener el afloramiento a un mínimo en la Corriente del Perú, aunque hubo también períodos más cortos en los que los gradientes de presión fueron muy superiores a lo normal. La media de las presiones mensuales según los datos del International Geophysical Year de 1957-1958, revelaron una reducción en los gradientes de presión frente a Sudamérica similar en tiempo a los de 1972 (Figura 14).

Si se promedian los datos de los gradientes de presión de 1972-1973 presentados en la Figura 14a cada mes, la curva resultante, que indica la desviación del gradiente de presión normal (media a largo plazo), presenta cambios estacionales similares a la curva del gradiente de presión de 1957-1958. Aunque el índice del gradiente de presión en la Figura 14 muestra solo un índice aproximado de la fuerza de los vientos de levante frente a Sudamérica, indica que ocurren frecuentes interrupciones o debilitamientos en la fuerza del viento en la Corriente del Perú en los años del Niño, y que estos debilitamientos se reflejan en las temperaturas superficiales del mar en las estaciones costeras sudamericanas.

En la Figura 14b, se despliegan las desviaciones de la TSM de la media a largo plazo de la TSM en Puerto Chicama, para mostrar el acuerdo con las fluctuaciones en el gradiente de presión. Parece que las grandes desviaciones negativas de la TSM siguieron un gradiente de presión superior a lo normal a fines de 1971 en la temporada de verano austral. Un aumento agudo en la TSM en Puerto Chicama fue evidente después de mediados de febrero correspondiendo en tiempo a grandes desviaciones negativas de presión frente a la costa sudamericana. Luego, se debilitó el gradiente de presión durante períodos prolongados, especialmente en junio y agosto 1972 (Figura 14a). Las desviaciones más grandes de la TSM de la media a largo plazo se encuentran durante este período (Figura 14b). Después de septiembre los períodos de los vientos alisios más débiles del sudeste fueron mucho más cortos, y la TSM fue casi normal hasta fines de noviembre. El segundo calentamiento y el más pronunciado apareció en diciembre después de una reducción aguda del gradiente de presión. En esta época dos aumentos cortos en el gradiente de presión reflejaron aparentemente solo aumentos temporales en los vientos alisios del sudeste. La conclusión del calentamiento costero y el principio de un rápido enfriamiento fueron aparentes después de febrero de 1973, 1 año después de haber comenzado el Niño.

COMENTARIOS FINALES

En 1972-1973, como en otros períodos del Niño, la tendencia del calentamiento del océano empezó en el área de la Corriente del Perú frente al Ecuador y Perú, y se extendió al occidente y al polo en ambos hemisferios con la llegada del invierno austral. En esta época, las mayores convexidades y depresiones de alta presión cambiaron aparentemente su posición normal en el hemisferio austral permitiendo que penetrara una sucesión de sistemas de baja presión de latitudes medias en los tropicos del hemisferio austral. Esto resultó en una reducción de los gradientes de presión de la superficie sobre una gran porción en la región del Pacífico oriental del sur y por lo consiguiente el debilitamiento de los vientos alisios del sudeste a lo largo de la costa sudamericana, al norte de los 15°S y a través del ecuador. Debido al debilitamiento de los vientos alisios del sudeste, el afloramiento disminuyó y otros procesos de interacción aire-mar afectaron de tal manera que las aguas superficiales de la Corriente del Perú y su extensión ecuatorial se calentaron a temperaturas superiores a lo normal.

La causa o causas de los cambios anómalos en el océano y la atmósfera sobre el Pacífico del sur no se conocen completamente y se necesita investigar mucho más para determinar el grado de intercambio océano-atmósfera durante un fenómeno del Niño. Es muy probable que una vez que el calentamiento ecuatorial principia, la atmósfera se transforma localmente por el aumento sensible de calor que se encuentra en el océano. Como resultado, la nubosidad baja disminuye sobre la Corriente del Perú y una cantidad mayor de energía solar alcanza la superficie oceánica.

En el futuro, los satélites colocados sobre el área ecuatorial deben ayudar a descubrir el comienzo y la magnitud de los fenómenos del Niño al obtener frecuentemente datos sobre la temperatura terrestre y nubes. Por ejemplo, los datos de los satélites de ATS3 y NOAA2 revelaron una reducción significativa en los estratos de nivel bajo a lo largo de las costas del Ecuador y al norte del Perú durante el Niño de 1972-1973. Nubes finas de estratocúmulos con grandes aberturas en la cubierta de nubes se vieron usualmente según las fotografías del satélite en 1972 cuando las anomalías positivas de la TSM eran extensas a lo largo de la costa sudamericana. A veces cuando la región de la Corriente del Perú era fría, una capa gruesa de estratos se extendía comúnmente al oeste y al ecuador sobre el agua fría. Quinn y Burt (1970) indicaron además el uso potencial que podría obtenerse de los datos del satélite al vigilar las condiciones del Niño.

El Niño de 1972-1973 fue intenso, y sus efectos ampliamente distribuidos a lo largo de la costa sudamericana. Por ejemplo, las condiciones atmosféricas y la pesca de anchoveta fueron aparentemente afectadas marcadamente por las condiciones caldeadas del agua. A lo largo de la costa sudamericana, empezaron a caer fuertes lluvias tropicales en diciembre de 1971 y se extendieron hacia el sur a medida que se desarrollaba el fenómeno del Niño. En Guayaquil, Ecuador, la lluvia tuvo un promedio de 11 pulgadas (275 mm) por mes entre enero y abril de 1972, que es 10 veces la lluvia mensual normal. Las lluvias tropicales amainaron algo durante abril y mayo del Ecuador al Perú, pero aumentaron de nuevo fuertemente en junio a lo largo de la costa en la región central del Perú. Hubo otra calma en las lluvias tropicales de agosto a noviembre. Sin embargo, a medida que las temperaturas del océano ascendieron a un alto grado en la Corriente del Perú en diciembre de 1972 y enero de 1973, se renovaron las lluvias tropicales (en enero de 1973 cayeron 701 mm en Guayaquil) y causaron inundaciones en Perú y Ecuador.

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MFR PAPER 1165

Japan's tuna fishery faces a major depression as catch rates decline, oil prices triple, and U.S. imports shrink.

Japan's Fisheries, 1975

TAMIO OTSU

TUNA INDUSTRY DILEMMA

The Japanese tuna industry this year is facing a major depression, a situation which has developed following the "oil shock" of 2 years ago and the subsequent inflationary trend. The problems are compounded by generally declining tuna longline catch rates and depressed tuna prices. When compared with the "mercury shock" of about 4 years ago, or the "canned tuna decomposition" problem of 3 years ago, both of which caused heavy losses to the tuna industry in Japan, the present situation is considered far more serious. Some sources predict that perhaps as many as 20 percent to 30 percent of the tuna longline vessels will soon become inactive, with many going into bankruptcy. The problem and causes are complex, but some of the more obvious reasons for the present state are these:

1. Tripling of oil prices in the last year.
2. Increased cost of fishing gear (particularly those oil-related products) and provisions needed for extended fishing operations.
3. Generally declining catch rates throughout the areas of operation.
4. Depressed fish prices in Japan.
5. The virtual closing of the U.S. markets to Japanese exports of albacore and yellowfin and skipjack tunas.

These problems are not restricted to Japan alone; they affect Korea and Taiwan and other tuna fishing nations as well. Korea and Taiwan may be even more affected since their longline vessels fish strictly for the export market, whereas a segment of the Japanese longline fleet fishes primarily for the domestic "sashimi" market. This is not to say that vessels fishing for the domestic market are not also having their problems at this time.

The increased oil prices, having gone from $40-$50 per ton a year or so ago to the present $110-$130 per ton, have resulted in a daily fuel cost of more than $400 for vessels that burn about 3.5 tons of fuel per day (e.g., many of the Korean vessels in the 220-280 ton category). Added to this is the high cost of fishing gear and other provisions needed for extended fishing trips. Meanwhile, catch rates have been declining in all oceans where these longline vessels fish. Reports indicate that catches in some areas have now fallen to less than 1 ton per day of fishing. A recent report from American Samoa shows that albacore catches have fallen far below a ton a day. It is easy to see that ex-vessel revenues of $500-$550 per day will not pay for the present high cost of operations.

The longline vessels (Korean and Taiwanese) based in American Samoa have had to extend their fishing grounds farther and farther away from the base. Fishing trips have increased in length to about 6 months for the larger vessels of about 250 tons, while 140-ton vessels are out 3 to 4 months. And still many of the vessels are returning to port with less than a full load. A source believed that about 30 Korean vessels would soon leave American Samoa, probably to return to Korea.

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Editor's Note

Early in 1975, Tamio Otsu attended the Japanese Tuna Research Conference, Shimizu City, Japan, as he has for the past 6 years. After the conference he spent two more weeks in Japan conferring with fishery biologists and members of the Japanese fishing industry with whom he maintains close ties. This article, written in late March 1975, summarizes his findings.

Probably most serious of all is the virtual closure of the American market to Japanese exports of albacore and yellowfin and skipjack tunas. Japanese sources reported that the U.S. canners have built up a large inventory of canned tuna as well as raw materials, and that they are no longer importing tunas from Japan (and presumably from other countries) or are offering prices for these fish that are agonizingly low. They attribute the large inventory to such causes as: 1) declining meat prices in the U.S.; and 2) bad publicity given "contaminated" canned tuna recently, both resulting in lower U.S. tuna consumption. Some expressed hope that U.S. consumption of fish would increase during the Lenten season and U.S. canners would then resume importing.

During my visit the newspapers and weekly magazines in Japan were giving considerable coverage to the financial problems of the Nichiro Gyogyo Kaisha. They reported that poor management had caused the company to overextend its operation to the point of near-bankruptcy. The company president and others in positions of leadership were removed and replaced by bank officials, and many of the executives were demoted in rank. The company reported that tuna and skipjack operations were to be terminated, and that 633 employees connected with this division would be released.

There are 13 Nichiro-owned skipjack tuna fishing vessels based in Tema, Ghana. The company decided to tie up all of the vessels, return the men to Japan, and terminate their employment. Subsequently, however, the powerful Seamen's Union in Japan has apparently forced Nichiro Kaisha to retract these plans (according to a news article dated 20 February). One company official told me that these 13 skipjack tuna vessels had been built especially for operation in the waters off West Africa and are not suitable for Japanese waters. They are built with very low freeboard, and fishermen fish off the sides and stern, but not at the bow as on traditional Japanese skipjack tuna vessels. The disposition of these vessels is a big problem, he said.

The reasons given for the problems encountered in the Ghana operation were: 1) low prices offered for skipjack and yellowfin tunas by the U.S. canner; 2) ICCAT (International Commission for the Conservation of Atlantic Tunas) regulations setting forth minimum sizes of yellowfin tuna to be taken off West Africa, which make operations difficult; and 3) increased cost of operations. Certainly this must be a simplified explanation of the problems faced by the Nichiro Kaisha, but it points to the generally depressed condition throughout the tuna industry.

During the "mercury shock" when the tuna fishery was faced with plummeting fish prices and decreased consumption, the Federation of Japan Tuna Fisheries Cooperative Associations (Nikkatsuren) did much to ease the problem. The Nikkatsuren carried out an intensive promotional campaign to assist in the recovery. They also purchased considerable amounts of fish, particularly albacore, and held them in freezers to stabilize prices. As a countermeasure to today's problem where Japan is unable to export its fish, Nikkatsuren apparently is planning construction of more freezers in order to purchase and store away the fish until the present situation eases.

Another serious problem faced by the tuna industry (particularly the producers) is that they have no direct control over prices. The depressed prices are attributable, in part, to the import of tunas into the Japanese markets directly by foreign fishing vessels. Vessels from Korea, Taiwan, and those flying the Panamanian flag (but manned mostly by Koreans) are delivering fish to Japanese ports. Such imports of fish amounted to 60,000 tons in 1974 and the amount has increased year after year. This situation is apparently unavoidable under present Japanese law. Because most of these imports are from Korea, negotiations were carried out recently to see if they would limit the amount of tuna delivered directly. The Koreans have apparently agreed to limit the number of vessels delivering directly to Japan to the present 160 vessels, or approximately a third of the Korean longline fleet. No agreement was reached on the amount to be delivered, however.

The foregoing account is based on scattered information provided by numerous sources and some of the statements are unverified. It is certain that the problems facing the Japanese tuna industry are given here in a most simplified form. Nevertheless, the important message is that the people in the industry consider the situation most serious, and that the Japanese word "fukyō" (depression) is most commonly used to describe the Japanese tuna fishery today.

PURSE SEINING IN THE WESTERN PACIFIC

For several years now, the Japanese have been sending chartered seiners to the western equatorial Pacific to conduct exploratory purse seining for skipjack and yellowfin tunas. Initially, the Japan Fisheries Agency undertook this work, and it was later carried on by the Japan Marine Fisheries Resource Research Center (JAMARC). It has now come to the stage where the Japanese consider purse seining to be commercially feasible, and several commercial seiners are operating in the western Pacific and in the Coral Sea. Catches are averaging close to 10 tons per set; the vessels are achieving success in catching fish in 80 percent of the sets made. The average catches are lower than in the eastern tropical Pacific purse seine fishery, but these Japanese seiners are considerably smaller than the average U.S. seiners, most being from 250 to 500 gross tons in size.

The Japanese initially found it extremely difficult to successfully set around the schools as the fish tended to escape before the net could be pursed. They also found that certain types of schools were more difficult to capture than others, and that the time of day seemed to make a great difference. Today, the Japanese believe that they can achieve success under the following conditions:

1. Schools must be associated with drifting objects (driftwood, etc.).
2. Sets must be made either early in the morning or at dusk.
3. Nets must be larger than those used in the eastern Pacific.

Consequently, the fishing masters on the seiners constantly search for drifting objects and associated schools, and when such a school is found they often follow it until early morning (tracking it overnight by marking the drifting object with radiobuoy and lights) or dusk before making their set.

The purse seine nets used in the western equatorial Pacific (area north of Papua New Guinea) and in the Coral Sea are larger than those used in the eastern Pacific. The following examples of net sizes are provided:

Vessel	Area used	Size of net
Nippon Maru	Eastern Pacific and West Africa (U.S.-type seiner)	110 m deep × 1,025 m long or 118 m deep × 1,350 m long
Hayabusa Maru	North of Papua New Guinea	220 m deep × 1,600 m long
No. 58 Tokiwa Maru	North of Papua New Guinea	250 m deep × 1,960 m long
No. 55 Hakuryu Maru	Japan coastal waters for skipjack and yellowfin tunas	150 m deep × 1,500 m long or 220 m deep × 1,500 m long
Wakaba Maru	do.	220 m deep × 1,500 m long
No. 23 Taikei Maru	do.	200 m deep × 1,500 m long
No. 28 Kohoku Maru	do.	261 m deep × 2,025 m long
No. 85 Seishin Maru (two-boat seining)	do.	350 m deep × 1,700 m long
No. 7 Konpira Maru (two-boat seining)	do.	240 m deep × 2,400 m long

The results of the most recent charter cruises were reported by JAMARC as follows:

Vessel: *Fukuichi Maru*, 500 tons
Survey area: Around the Caroline archipelago
Survey period: 18 June-30 November 1974

First cruise

Departed Yaizu on 20 June 1974. Started survey southward beginning around the Bonin Islands, and worked as follows: 24-25 June, south of Hahajima; 1-8 July, west of the Carolines at lat. 6°-7°N, long. 141°-143°E; 9-15 July, east of Palau; 16 July-2 August, southeast of Palau at lat. 3°-4°N, long. 136°-138°E; 7-16 August, Western Carolines at lat. 4°-6°N, long. 142°-147°E.

Made a total of 27 sets and caught 229 tons of skipjack tuna and 53 tons of yellowfin tuna for a total of 282 tons. The catch per set amounted to 10.4 tons; the maximum catch was 32 tons per set. A full load was obtained on 16 August so the survey was terminated and the vessel returned to Yaizu.

Second cruise

Fukuichi Maru departed Yaizu on 2 September en route to fishing grounds. Started fishing in waters southeast of Palau. Fishing was not as good as on the earlier cruise. Worked in area lat. 0°-8°N, long. 135°-145°E, and on 7 October arrived in Guam, where they unloaded 22 short tons of skipjack tuna. Only 10 sets had been made for a catch of 22 tons of skipjack tuna and 33 tons of yellowfin tuna, a total of 55 tons.

Third cruise

Fishing commenced on 12 October in the area lat. 4°-8°N, long. 145°-151°E (eastern Carolines). Three sets resulted in 18 tons of fish. In waters southeast of Palau at lat. 2°-5°N, long. 140°-145°E, 14 sets resulted in 127 tons of fish. Up to this point, fishing conditions were as poor as on second cruise. Only two sets had resulted in about 10 tons per set; others were on the order of 1-3 tons per set. However, toward the end of the survey period, on 6 November, a catch of 20 tons was made at lat. 2°N, long. 144°E. Since it looked as though fishing would improve after this, the cruise period was extended. The vessel fished until 18 November and returned to Yaizu on 26 November.

During the charter period, the *Fukuichi Maru* fished 53 schools associated with drifting objects, and caught 168 tons of yellowfin tuna, 320 tons of skipjack tuna, and 12 tons of miscellaneous species, for a total of 500 tons. The target catch of 468 tons was exceeded by 32 tons.

According to JAMARC, there are now five or six commercial seiners working in the Coral Sea (lat. 15°S, long. 147°E) for yellowfin tuna.

The average catches as well as the success rate of seining in the western equatorial Pacific must be considered in the light of fishing effort. If vessels avoid making sets during midday, this cuts down fishing effort considerably. The size of the seiners (small relative to U.S. seiners) may be the saving grace in this particular fishery.

Because Japanese seiners are so completely dependent upon drifting objects in order to make successful sets on skipjack and yellowfin tunas in the western equatorial Pacific, Japanese researchers would like to develop artificial drifting objects that will aggregate tunas for seining. Studies have already indicated that there is promise in this approach.

JAPANESE SOUTHERN WATER SKIPJACK TUNA FISHERY, JULY 1974-JANUARY 1975[1]

July-August 1974

Because fishing was poor in the Marianas area, many of the larger vessels (larger than 299 tons) went south and fished around lat. 3°-6°N, long. 143°-158°E, as well as around lat. 1°N, long. 168°-173°E (Figs. 1 and 2). Initially, the catches ranged from 3 to 20 tons per day, averaging between 5 and 7 tons, with considerable variation from vessel to vessel. The first part of August the fishing grounds east of long. 160°E became very unproductive. Vessels shifted westward to lat. 2°-6°N, long. 145°-155°E, where fishing was somewhat better; there some vessels took more than 30 tons per day. However, results were mixed, and the fishing condition was generally unstable. Of the skipjack tuna taken, 70 percent-75 percent were 3-4 kg fish.

At the end of the albacore season, there were vessels which ventured eastward from the Emperor Seamount towards the Hawaiian Islands. These vessels reported maximum catches of 20-25 tons per day, but average catches were between 7 and 8 tons (including small yellowfin tuna). In this area (northwest Hawaiian Islands) large skipjack tuna of 9-15 kg are usually quite abundant, but this year such large fish were few and about 70 percent of the catch consisted of 1.5-4.0 kg fish.

In August, there were 50-60 vessels fishing in southern waters and about 20 vessels operating near the northwest Hawaiian Islands. The landings of southern water fish at Yaizu during July-August were as follows:

July

Twelve vessels unloaded 751.4 tons; the average landings per vessel amounted to 62.6 tons (including 17.9 tons of small yellowfin tuna). From the waters around the northwest Hawaiian Islands, four vessels unloaded 721.8 tons, averaging 180.4 tons per vessel (including 101.1 tons of small yellowfin tuna).

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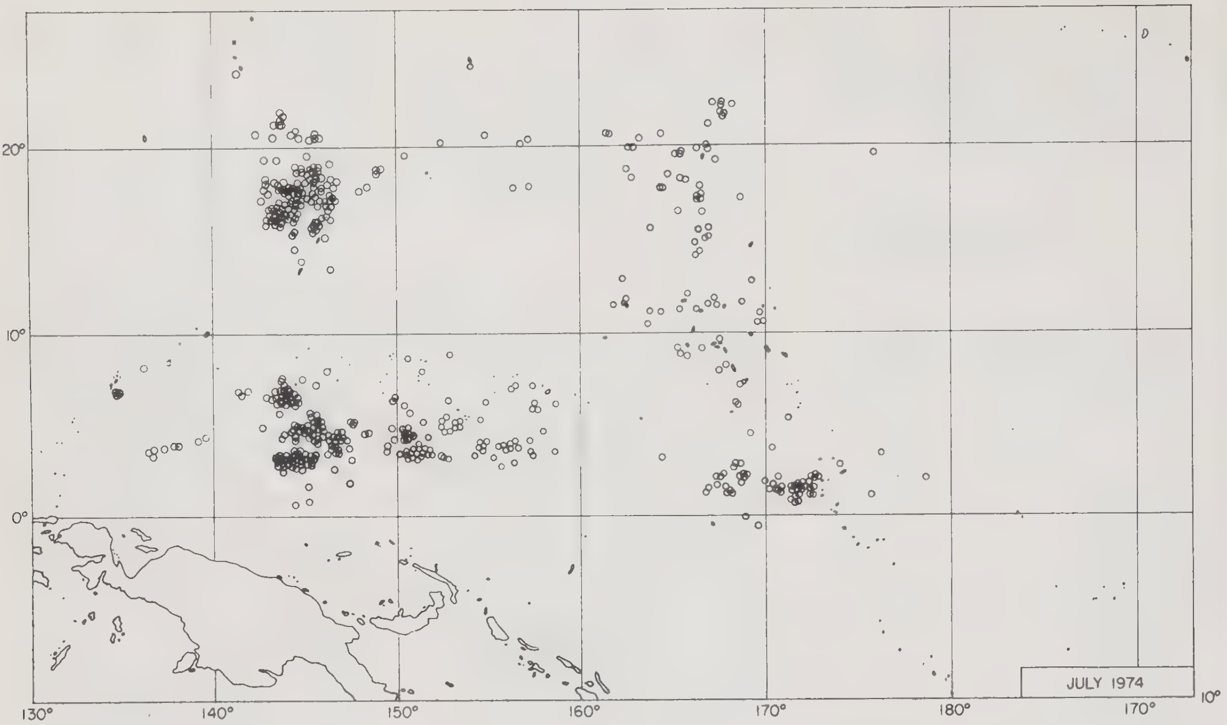
[1] From a preliminary report prepared by Tamotsu Tanaka, Yaizu Branch, Tohoku Regional Fisheries Research Laboratory.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10°
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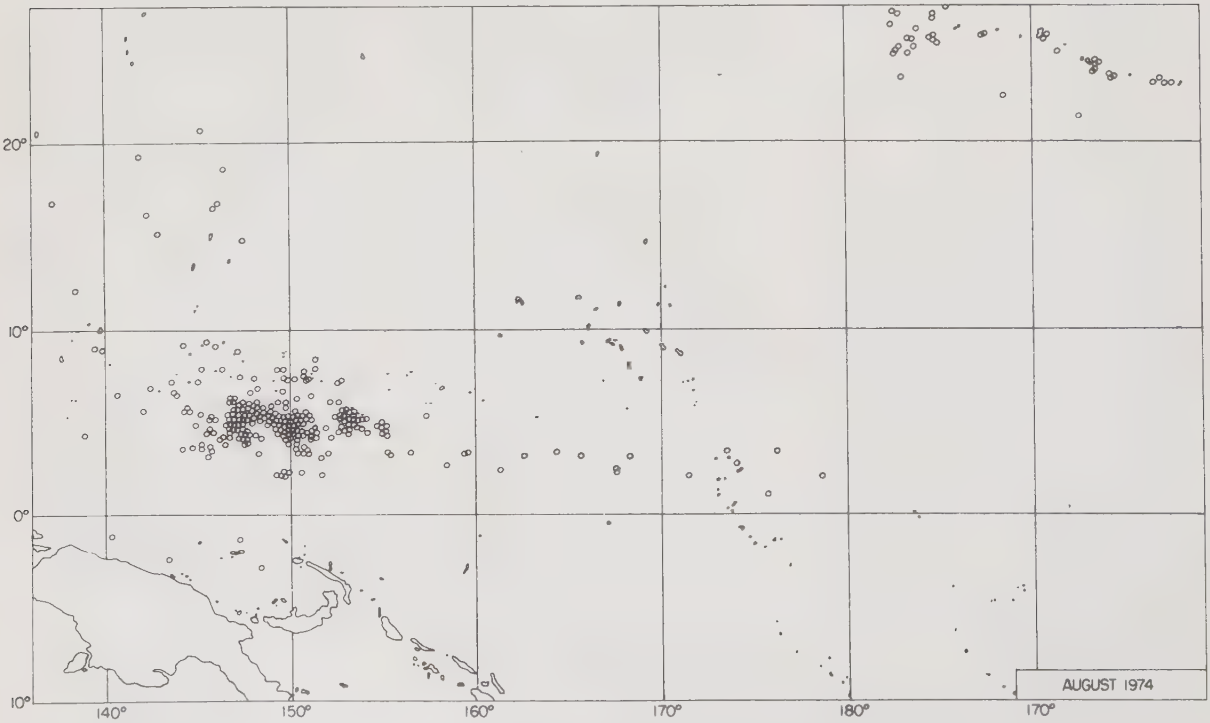
JULY 1974

Figure 1.—Location of skipjack tuna catches, July 1974.


20°
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160°
170°
180°
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AUGUST 1974

Figure 2.—Location of skipjack tuna catches, August 1974.

August

Sixty-one vessels unloaded 5,675.5 tons (including 99.9 tons of small yellowfin tuna), averaging 93.0 tons per vessel. One purse seine vessel unloaded 192.2 tons of skipjack tuna and 83.5 tons of small yellowfin tuna. From the waters near the northwest Hawaiian Islands, six vessels delivered 655.0 tons (including 55.9 tons of small yellowfin tuna); the average landing per vessel amounted to 109.1 tons.

September 1974

In September (Fig. 3), most of the vessels over 299 tons shifted to the southern water skipjack tuna fishery and the fishing grounds expanded widely in an east-west direction. There were 130-140 vessels in the fishery. Fishing continued to be poor, with daily catches of 2-15 tons, averaging around 4 tons per day. The waters south of the equator were scouted but no good fishing grounds were located. Although fishing conditions had been poor since July, considerable numbers of fish schools (with bird flocks) were reportedly being seen in waters west of long. 145°E to the vicinity of Palau. However, the fish were poor-biting, and the maximum catches were 7 or 8 tons per day. The average catches amounted to around 3 or 4 tons per day. As in July-August, the fish sizes were 3 or 4 kg for the most part. In the vicinity of the equator as well as in waters west of long. 145°E, fish of 1.5-2.0 kg generally make up 10 percent to 20 percent of the catch. This year, however, such small fish were reported to be very scarce.

The water temperatures in the fishing grounds west of long. 150°E were 29.5°-30.7°C, higher than usual by 0.5°-1.0°C. In these higher temperatures, the baitfish suffered considerable mortality. In most years, the vessels report some baitfish mortality around lat. 20°N when encountering high water temperatures. However, the survival is usually good thereafter, and the remaining baitfish can be used on the fishing grounds. This year, however, the high temperatures on the fishing grounds appeared to have caused additional mortality. Many vessels reported mortalities greater than 60 percent. As a result, the tuna catches were also poor, and many vessels returned to port with less than 50 tons of fish. Even those vessels that managed to maintain their baitfish supply encountered such poor fishing that they had to spend 26-30 days on the fishing grounds, thus extending the trip to 35-45 days.

In September, 50 vessels unloaded 4,310.6 tons of fish at Yaizu for an average delivery per vessel of 86.2 tons (including 111.5 tons of small yellowfin tuna). One vessel returning from east of the international dateline delivered 106.5 tons (including 14.5 tons of small yellowfin tuna).

October 1974

The fishing grounds in October (Fig. 4) extended broadly from the Caroline Islands to the northern part of the Solomon Islands. In all areas, vessels reported seeing considerable numbers of fish schools. However, the fish were not responding well to chumming and catches were poor. Throughout the Caroline Archipelago, the water temperatures were higher than usual by 1.0°-1.5°C, being reported at 29.5°-31.0°C. There were many reports of

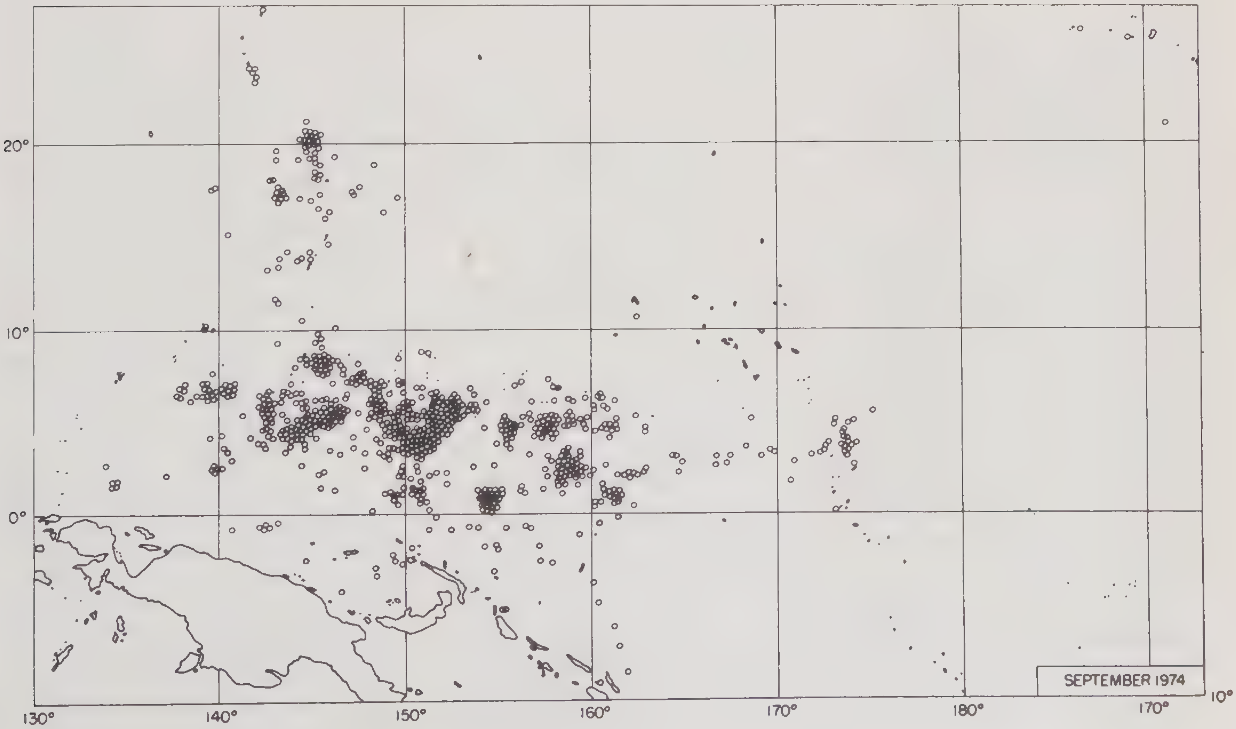

Figure 3.—Location of skipjack tuna catches, September 1974.

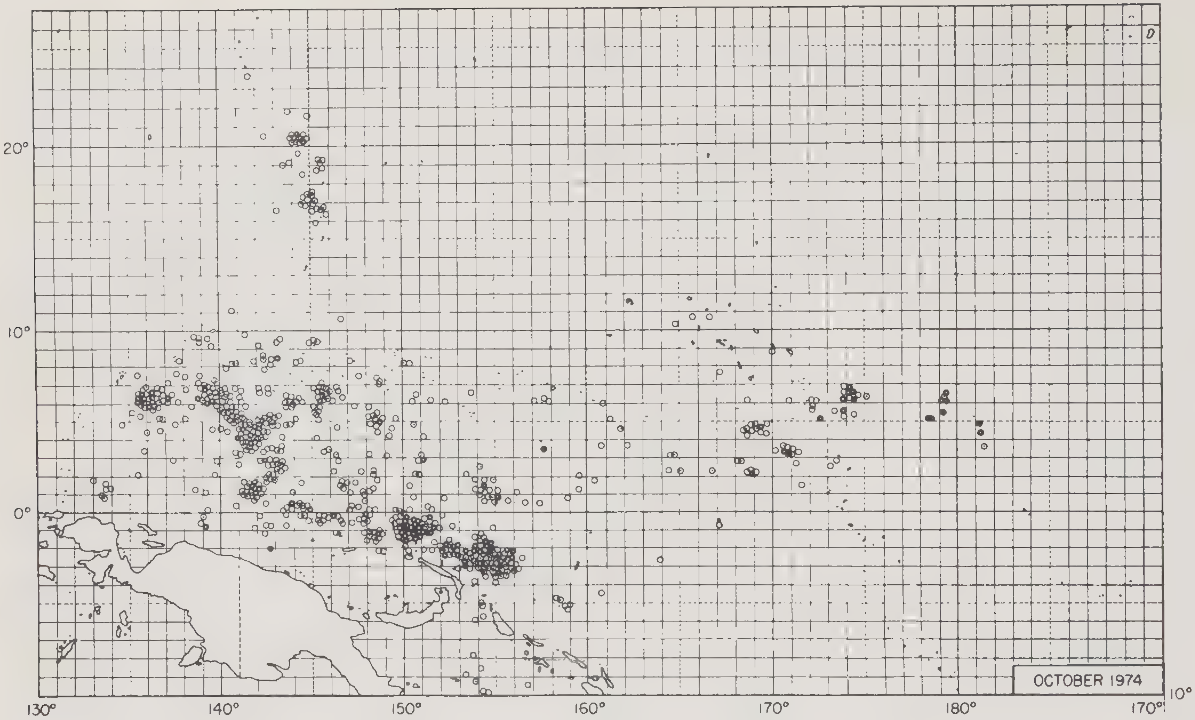

Figure 4.—Location of skipjack tuna catches, October 1974.

heavy baitfish (anchovies from Japan) mortality, a condition that first started in September. The effect of temperature on baitfish was being felt by all vessels that had gone to southern waters at the end of the albacore season in Japanese coastal waters.

Many vessels fished in the area bounded by lat. 3°-6°N, long. 136°-145°E in early and mid-October. Towards the end of the month the effort shifted to the waters north of the Solomon Islands (lat. 0°-3°S, long. 150°-156°E). The catches improved some, but there was still considerable variation among vessels, and fishing conditions continued unstable. Only a few vessels returned to port with catches exceeding 100 tons. In early- and mid-October, the maximum catches were reported to be 10-15 tons per day, averaging 3-4 tons per day; towards late October, the maximum catch was 32 tons, averaging 5-6 tons per day. The skipjack tuna ranged in weight from 1.8 to 3.5 kg, and averaged 2.5 kg. There were about 120 vessels fishing in southern waters during the month.

The fishing grounds in the waters extending from the Gilbert Islands to the Marshall Islands, usually good at this time of the year, turned out to be very poor this year. Fishing was particularly poor in the Marshalls north of lat. 8°N, where schools were reportedly very scarce. In waters south of lat. 7°N, schools were also scarce but were better biting and catches of 7-10 tons per day were reported. There were 10-15 vessels in the Gilberts-Marshalls area.

On the other hand, vessels fishing east of the international dateline reported good catches of 18-32 tons per day. The water temperatures in the area ranged from 28.5° to 29.2°C. The fish sizes ranged from 3 to 7 kg.

In late October, two skipjack tuna vessels went to the Coral Sea to handline for tunas. These vessels caught 60 tons and 18 tons, respectively, of bigeye and yellowfin tunas. Two purse seiners in the Coral Sea reported taking a total of 200-250 tons of tunas.

In October, 96 vessels delivered a total of 7,913.3 tons of fish, averaging 82.4 tons per vessel. At the same time last year, 83 vessels landed 10,874.8 tons, averaging 131.0 tons per vessel.

November 1974

Within the area bounded by lat. 2°S-5°N, long. 141°-146°E, the northern and southern boundaries provided good fishing and many of the vessels began shifting their efforts accordingly (Fig. 5). The maximum day's catch was reported at 30 tons; the average catch was around 4-5 tons per day in both areas. The skipjack tuna were 2-6 kg in size. Most of the 35-40 vessels fishing there were large.

In the vicinity of the Gilberts at lat. 1°-2°S, long. 172°-174°E, good fishing occurred for a very short time. Soon thereafter, good fishing was reported at lat. 4°N, long. 168°-169°E, where toward late November catches of 30 tons were reported. There were 50-60 vessels in the vicinity.

Some vessels worked farther to the east of the international dateline than they had in October, and reached the vicinity of lat. 5°-6°N, long. 163°W. But

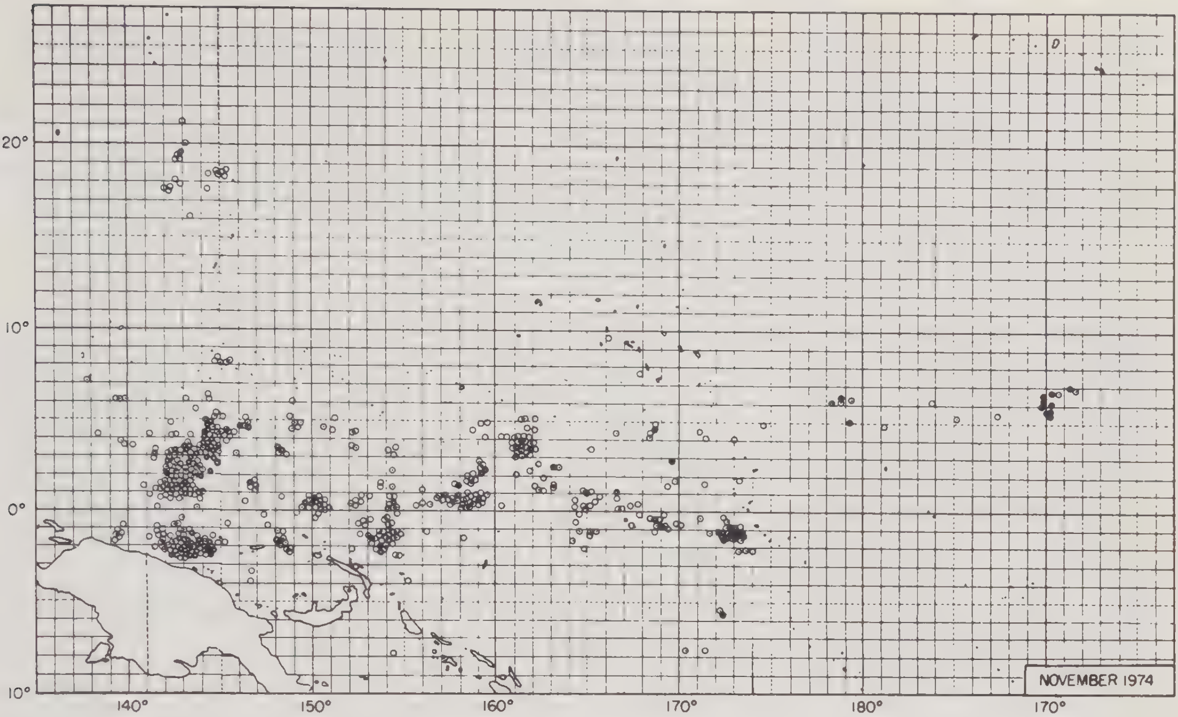

Figure 5.—Location of skipjack tuna catches, November 1974.

they fished mainly around lat. 5°-7°N, long. 168°-171°W where the water temperatures were 28.2°-28.3°C. Maximum catches were around 50 tons per day. The size composition of the skipjack tuna was as follows: larger than 6 kg, 24 percent; 4.5-5.9 kg, 72 percent; 2.5-4.4 kg, 4 percent. Thus, virtually all of the fish were large, weighing more than 4.5 kg.

A vessel entering the port of Makurazaki reported sighting numerous large schools of very small skipjack tuna (around 10 cm long).

In late November, the *No. 3 Inasa Maru* from Tago in Shizuoka Prefecture and three other vessels caught considerable amounts of "doku-uroko ibodai" (*Tetragonurus atlanticus*) around a night light at lat. 3°N, long. 161°E, where the water temperature ranged from 29.0° to 29.4°C. Using this "high seas" baitfish, the vessels experienced good results in skipjack tuna fishing. This is probably the first time that baitfish has been taken in quantity on the high seas in southern waters. It is desirable to conduct detailed studies on this potential baitfish resource in the future.

December 1974

Five separate fishing grounds developed during the month (Fig. 6) as follows:

1. Lat. 9°-17°N, long. 130°-135°E

Most of the vessels fishing in this area were from Kagoshima Prefecture, but a few were from Mie Prefecture. In early December, the main ground formed at lat. 17°N, long. 133°-134°E. The ground gradually shifted southward. Later in the month it was at lat. 9°-10°N, long. 131°-133°E. The maximum catch amounted to 20-25 tons and the average was around 7 or 8 tons per day. Fishing conditions were stable; the skipjack tuna weighed 5-6 kg. There were about 30 vessels in the area.

2. Lat. 2°S-5°N, long. 139°-145°E

In this area, the fishing grounds formed along the northern and southern borders similar to the previous month. Fishing was rather poor with a maximum catch of 25-30 tons per day and an average catch of 4 or 5 tons per day. Fish schools were reportedly numerous, however. As for fish sizes, the skipjack tuna taken along the southern border weighed 3-5 kg; those along the northern border were 3-6 kg. The fish along the southern border were somewhat larger than in other years.

3. Lat. 3°-6°N, long. 164°-170°E

There were 30-40 vessels fishing this area; the average catch amounted to 4-5 tons per day. Maximum catches were around 18-20 tons per day and the skipjack tuna weighed 3-6 kg.

4. Lat. 5°-8°N, long. 172°-176°W

The water temperature in the area was 28.0°-28.3°C. Fishing continued to be poor through mid-December. There were 15-20 vessels venturing eastward to this area. Towards late December, the catches reached about 20 tons per day. The vessels reported winds of force 3 or 4 in the area. Some experienced rather good fishing and five or six vessels returned to port with full loads. The skipjack tuna size composition was as follows: larger than 6 kg, 2 percent; 4.5-5.9 kg, 51 percent; 2.5-4.4 kg, 43 percent; 1.5-2.4 kg, 1 percent.

5. Lat. 7°-9°S, long. 150°-155°E

The water temperature in this area (Solomon Sea) was 29.1°-30.0°C. Fishing grounds developed about 2 months earlier than in previous years but catches were poor, with a maximum of 20 tons per day and an average catch of 4 or 5 tons per day. The skipjack tuna weighed 1.5-3.5 kg; there were five or six vessels fishing this area.

January 1975

Fishing grounds developed in four locations (Fig. 7): 1) lat. 7°-9°S, long. 150°-155°E; 2) lat. 2°S, long. 152°-160°E; 3) lat. 8°S, long. 161°-163°E; 4) lat. 6°N, long. 175°-177°W.

1. Lat. 7°-9°S, long. 150°-155°E

The water temperature in this area (Solomon Sea) was 29.2°-30.0°C. Through mid-January, the catches were exceedingly poor, with vessels reporting catches of 3-5 tons per day. In late January, the fishing improved and catches of 10-20 tons per day were seen here and there. Numerous reports were received of schools associated with whale sharks. Fishing such schools, the proportion of small yellowfin tuna and small bigeye tuna of 3-7 kg increased to 5 percent to 10 percent of the total catches.

The skipjack tuna size composition was as follows: larger than 4.5 kg, 5.5 percent; 2.5-4.4 kg, 55.5 percent; 1.5-2.4 kg, 39 percent. There were 30-40 vessels fishing the area.

2. Lat. 2°S, long. 152°-160°E

Water temperature in the area was 29.2°-29.5°C. Most of the schools were associated with bird flocks. Catches averaged around 5 or 6 tons per day, with a reported maximum catch of 25 tons. In late January, catches improved to around 8-13 tons per day and fishing conditions continued to be rather stable. The skipjack tuna were mostly (80 percent to 90 percent) between 3.0 and 3.5 kg. There were 30-40 vessels in the area.

3. Lat. 8°S, long. 161°-163°E

The water temperature was reported to be between 29.0° and 29.5°C. in this area located north of Guadalcanal. In late January, the catches averaged 7-8 tons, and the maximum reported was 20 tons per day. Some vessels moved to this area from farther west, until there were 10-15 vessels fishing here. The skipjack tuna taken were 3.0-3.5 kg in size.

4. Lat. 6°N, long. 175°-177°W

The water temperature was 27.0°C. Weather conditions were unfavorable with winds of force 3-4 prevailing. In

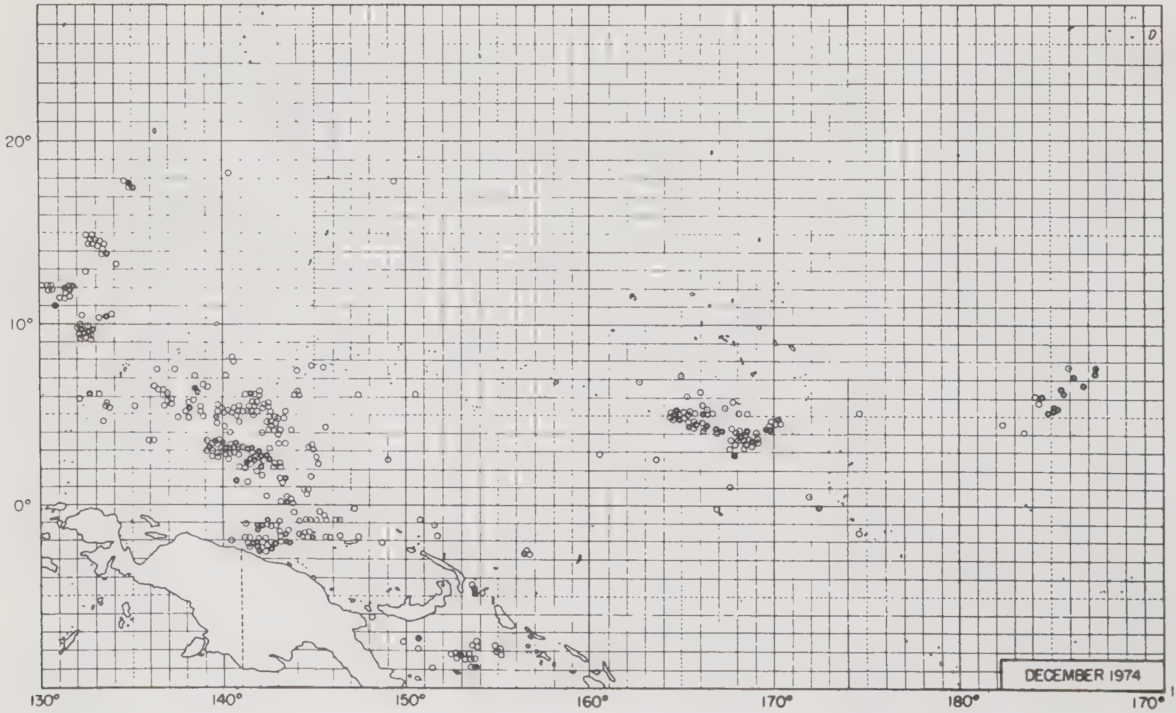

Figure 6.—Location of skipjack tuna catches, December 1974.

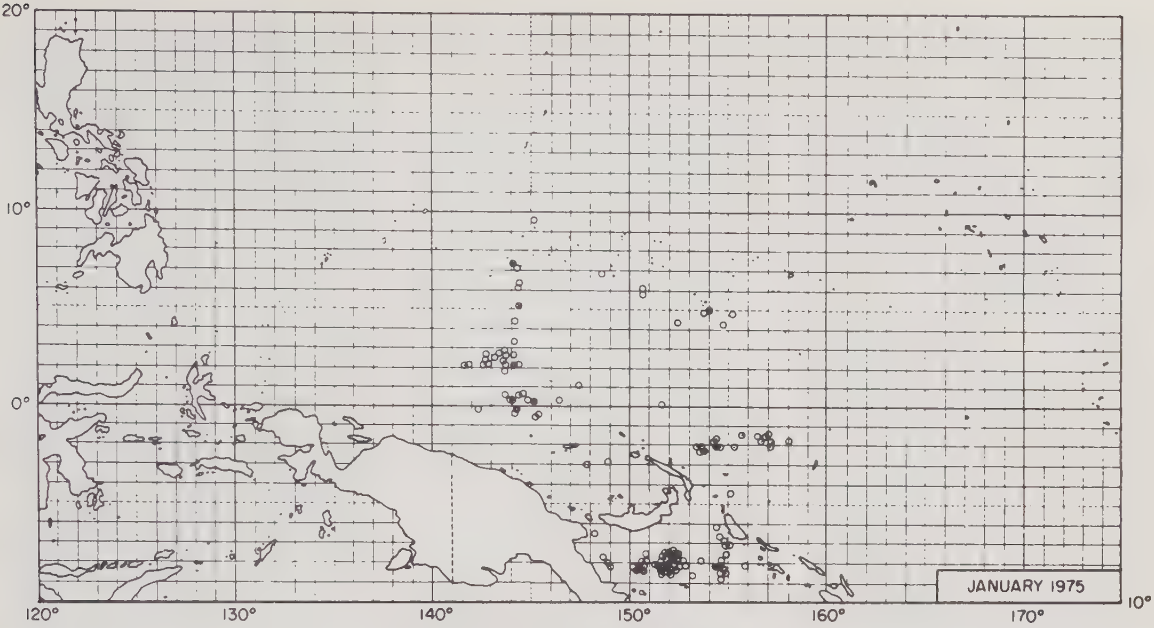

Figure 7.—Location of skipjack tuna catches, January 1975.

late January, catches were up to 30-49 tons in some cases and three vessels returned home with total catches of 190-220 tons. The skipjack tuna size composition was: larger than 6 kg, 17 percent; 4.5-5.9 kg, 62 percent; 2.5-4.4 kg, 20 percent; and 1.5-2.4 kg, 2 percent. There were around 20 vessels fishing this area.

In general, fishing conditions during the July 1974-January 1975 period were quite poor throughout southern waters as compared with the previous year. The reasons can be partially attributed to heavy bait mortalities, at least during September and October 1974. Furthermore, though vessels reported sighting numerous schools, they found the schools generally "poor-biting."

SKIPJACK TUNA FISHERY SURVEY IN MICRONESIA

For the last several years the Japan Marine Fisheries Resource Research Center (JAMARC) has been conducting skipjack tuna fishery surveys in various places in the Pacific. In 1972 and 1973, JAMARC sent a chartered skipjack tuna fishing vessel to survey the waters of New Hebrides, New Caledonia, Nauru, Tonga, and Wallis Islands. The results were generally poor, as I reported in last year's trip report. JAMARC concluded that of the various islands surveyed for live bait and for skipjack tuna fishing, New Caledonia held the greatest potential. The insufficiency of baitfish was generally the principal problem. Even in New Caledonia, JAMARC researchers found baitfish to be rather scarce.

In 1974 JAMARC chartered the *No. 20 Akitsu Maru*, a 190-ton skipjack tuna vessel, to survey Micronesian waters. The survey period extended from 1 July through 15 October 1974. The following is the report on the charter cruise.

The vessel departed Kurihama on 4 July and fished for 6 days in waters between the Bonin Islands and Saipan. Fishing was poor and the catch totaled only 8 tons. The vessel entered the ports of Saipan (15-19 July) and Truk (22-24 July) and discussions were held with local authorities regarding the fishery survey of the Truk area. However, no definite agreement could be reached so the survey of Truk was temporarily suspended.

On 26 July, the vessel entered Ponape, and again the officers met with local authorities. Here, the local authorities were quick to agree on the survey plan. The survey of Ponape was conducted between 5 August and 5 October following the successful negotiation.

A bait survey was conducted by sampling with a stick-held dip net, "bouke ami", 79 times, beach seine 10 times, and drive-in net, "oikomi-ami", 8 times. The most successful method was the use of the stick-held dip net at night on baitfish attracted to a night light. A total of 1,056 buckets of baitfish such as engraulids, clupeids, and atherinids (3 kg per bucket) was taken. The beach seine during the day caught 13 buckets, mainly of carangids and engraulids. The drive-in net, which is considered a difficult bait-catching method, resulted in only one bucket of baitfish. The latter method is used to catch reeffish such as apogonids.

Skipjack tuna fishing was conducted over 34 days during which 116 schools were fished for a total catch of 34 tons of skipjack tuna, and 0.2 ton of yellowfin tuna. The results were disappointing since the cruise target had been set at 105 tons. Observers cited the following reasons for the poor showing. Bait was scarce and sufficient quantities could not be taken; this often precluded the vessel from fishing during the best hours of early morning and late afternoon. Furthermore, some of the baitfish (anchovies in particular) were very weak, some were stronger but too scarce (clupeids), and some, although rather plentiful and strong, were too large in size (carangids).

JAMARC officials reported that they have received excellent cooperation from local officials and that they are being asked to continue the survey in Micronesia.

CAPTURING SKIPJACK TUNA LIVE BAIT ON THE HIGH SEAS

The well-being of the skipjack tuna pole-and-line fishery is dependent to a very large degree on how well and how long live bait can be maintained aboard the fishing vessels. For example, from 1973 to early 1974, the long-ranging skipjack tuna vessels were returning to Japan from southern waters with full loads of skipjack tuna, one vessel after another. However, beginning in the summer of 1974, perhaps due to unusually high water temperatures, the vessels began to experience heavy bait mortalities. Vessels began to report bait mortalities of 30 percent to 70 percent, and many vessels returned to port with very small catches.

Because live bait is so vitally important, the Mie and Shizuoka Prefectural Fisheries Experimental Stations have been devoting considerable effort toward the problem of maintaining baitfish on skipjack tuna vessels. They have worked on various approaches (as I have reported in previous trip reports) but the problems are far from solved at this time.

Because of the importance of live bait, however acquired, in skipjack tuna fishing, a recent occurrence created considerable stir among the industry people. As mentioned earlier, a skipjack tuna vessel from Shizuoka Prefecture reported catching baitfish on the high seas. The *No. 3 Inari Maru* (299 tons), at lat. 3°51'N, long. 161°15'E, managed to capture 50-60 buckets (3 kg per bucket) of a fish the Japanese call "dokuuroko ibodai," (*Tetragonurus atlanticus*) that had gathered around the light of a 500-watt lamp. The location was the eastern Carolines, about 180 miles south of Ponape. Using this baitfish, the vessel managed to capture 10 tons of skipjack tuna.

When informed of this, two other vessels from Shizuoka Prefecture, the *Tagoshima Maru* (299 tons) and the *Yasufuku Maru* (299 tons), also managed to catch this baitfish in the same general location.

Researchers believe that these fish, coal black in color, probably inhabit deep water. They were 4-7 cm in length and appeared to be a very satisfactory live bait for skipjack tuna fishing. They swam slowly at the surface when chummed and were readily fed upon by the tuna. Furthermore, it was possible to maintain these fish in bait-wells at least up to 16 days. The Japanese reported the need to study the distribution of these fish, their seasonality, and whether or not they can be taken in reliable quantities to further skipjack tuna fishing in southern waters.

BLUEFIN TUNA REARING

A program of "tuna culture and rearing" was financed by the Japan Fisheries Agency in 1970 with national, prefectural, and university laboratories involved in a cooperative effort. The lead agency was the Far Seas Fisheries Research Laboratory in Shimizu. This was a 3-year program which ended in 1973. However, before its termination, considerable progress had been made. Many tuna species were successfully fertilized artificially, eggs hatched, and the larvae reared to a certain size. Tunas were also reared from young taken in the wild. This was the case with the bluefin tuna: young fish taken in traps or by surface trolling in coastal waters were held in net enclosures, fed, and reared as long as possible. Originally, the difficult problem was to get the captive fish to feed during the cold winter months. Thus, the first hurdle was to "over-winter" the fish while maintaining some growth. The heavy mortality with the onset of low temperatures remained a major problem. Nevertheless, several of the research facilities reported various degrees of success in this effort.

Although the Kochi Prefectural Fisheries Experimental Station in Kochi, Shikoku Island, was not part of the original program, researchers there are also conducting rearing experiments. Kochi is ideally located for this project since winter temperatures do not fall below 15°C. (Bluefin tuna generally cease feeding when temperatures go below 15°C.) The rearing facility is located in Komame, Kochi Prefecture, near the southwestern tip of Shikoku Island. Komame is bathed by the warm waters of the Kuroshio, and the bay is blessed with an excellent circulation of clean oceanic water.

Young fish are captured by surface trolling or in traps generally during the latter half of the year. Fish smaller than 0.3 kg are found to be the hardiest for rearing purposes. The young fish are placed in the "kowari" (net enclosures) set up in the bay at Komame. They begin to feed in 3-7 days. The "kowari" is octagonal in design, 4.2 m to a side, 6 m deep. In general, growth of bluefin tuna is found to be very rapid. The fish grow from 0.1-0.2 kg to 2.5-3.0 kg in 6 months and to 10 kg by the end of the second year. The growth after the second year is estimated at 25-30 kg by the end of the third year, and 40 kg by the end of the fourth year.

The researchers reported that bluefin tuna rearing has a big advantage over yellowtail rearing (the latter is carried out commercially on a rather large scale in Japan). For example, they noted that bluefin tuna growth rate is much faster than yellowtail growth. Also, conversion of food to body weight is better in the case of the bluefin tuna (it was reported that 6 kg of food adds 1 kg of body weight in bluefin tuna whereas it requires 8 kg of the same food to add 1 kg of body weight in yellowtail). Both fish are fed mackerel, sardines, and the like.

Organoleptic taste tests have shown that bluefin tuna reared for 2 years were very similar in flavor and overall quality to fish taken in the wild, although fish reared only for 1 year were found wanting in flavor. The biggest advantage to bluefin tuna rearing is that they can be marketed at about 4 times the market price for yellowtail. Test marketing has shown that there is ready acceptability of fish reared for more than 2 years.

Although many fishermen who are now rearing yellowtail are beginning to show considerable interest in bluefin tuna rearing, many problems remain before the latter can be made commercially feasible. Unlike yellowtail, no large quantities of young bluefin tuna can now be taken to start a commercial rearing operation. Another problem is that bluefin tuna require much better quality oceanic water than do yellowtail. They are more readily susceptible to mortality from heavy runoffs or deteriorating water quality in the rearing area. In spite of these problems, the Japanese are optimistically looking to the day when commercial rearing of bluefin tuna, and perhaps other high-quality tuna species, becomes a reality.

USE OF LIVE BIGEYE SCAD AS LONGLINE BAIT

Last year I reported on the use of live bigeye scad, *Trachurus japonicus*, as longline bait in Oita Prefecture. In discussing this matter with researchers of the Nansei Regional Fisheries Research Laboratory, I learned that longline vessels of Kagoshima, Miyazaki, and Kochi Prefectures also use live bigeye scad as bait. These are the smaller coastal longline vessels, mostly under 20 tons.

Apparently, the fishermen of Miyazaki Prefecture were the first to use live bigeye scad in longlining. They began experimenting with this live fish as longline bait in experimental fishing for the dolphin, *Coryphaena hippurus*. Because it also did so well on tunas, this use has become quite widespread. Today, fishermen claim that live bigeye scad results in better than twice the catch rate obtainable with frozen bait.

Recently, however, bigeye scad has become a very expensive market fish. In Oita Prefecture, for example, where they have been rearing this fish for use as longline bait, the trend has been towards marketing it as food fish rather than as longline bait. If the price for this fish stays up, it will undoubtedly be used less as longline bait in the future. Coastal longline fishermen may experiment with other species.

ANTARCTIC KRILL

According to the Japan Marine Fisheries Resource Research Center (JAMARC), many nations indicated interest in the Antarctic krill resource during the October 1974 FAO meeting in Rome. As a result, FAO will begin to include krill harvest in its annual world fishery statistics, and information on the krill resources, survey results, etc. will be disseminated through FAO. The krill is an important unutilized resource that has the potential of solving some of the world's food problems.

According to JAMARC, there are about 80 species included among the "krill," 30 of which are euphausiids. A good example is *Euphausia superba*. This species grows about 3 cm per year and reaches a size of 5-6 cm in 2 years. It spawns from November through March, with each female spawning from 2,000 to 30,000 eggs depending upon its size. Life span is believed to be about 2 years.

Krill is the principal food of the baleen whales in the Antarctic. The resource has been variously estimated at from 100 million to 600 million tons; some estimates have been much larger. The maximum sustainable yield has been estimated at 50 million to 100 million tons. No matter, it is true that the krill resource is very large.

These tiny animals occur in swarms or patches which have been estimated to range from a few meters to as much as 10 km across. The swarms apparently appear at the surface during the day and sink at night. They are abundantly distributed between lat. 60° and 75°S, particularly in such locations as the Weddell Sea and the Scotia Sea, in waters with temperature ranging between 0.3° and 2.0°C.

The Japanese and the Russians are probably equally advanced in krill harvesting techniques today. Both report catching 1 or 2 tons per trawl tow, and catching as much as 10 tons per tow in exceptional cases. Both are using the midwater trawl, making tows between the surface and about 70 m in depth. The Russians are scouting for krill patches visually, while the Japanese report scouting visually as well as with fish finders. The Soviets are said to have about three stern trawlers of the 3,500-ton class harvesting krill.

JAMARC has for the last 3 or 4 years sent a chartered stern trawler to the Antarctic. The report on the present charter cruise is as follows:

Vessel:	*No. 11 Taishin Maru*, 1,500-ton stern trawler
Survey area:	Antarctic Ocean (Weddell Sea)
Survey period:	October 30, 1974-March 31, 1975

On 1 November, 1974 the vessel departed Cadiz, Spain and entered Cape Town on 26 November to make final preparations. It departed Cape Town on 29 November and arrived on the fishing grounds on 4 December and began searching for krill patches with a fish finder. Fishing began on 6 December at lat. 63°-65°S, long. 55°-66°E (northeast of Cape Ann, Enderby Land). By the end of December, it had trawled 166 times in 22 days catching 262 tons of krill. The largest catch per day during the period amounted to 25.7 tons; the best catch in a single tow was 7.1 tons.

JAMARC reported that as of 15 February, 1975 the vessel had taken 961 tons of krill. As far as catching technique is concerned, JAMARC officials are quite satisfied with progress made over the last 3 years of exploratory work. Although several types of nets had been prepared, only the midwater trawl seemed to work efficiently. It also had the advantage of being able to fish in winds of up to force 6 or 7. The midwater trawl had a mouth opening of 10 × 10 m, total length of 48.7 m. Trawling was done using special otter boards made of aluminum alloy of neutral buoyancy, 3.6 × 2.5 m in size. The method of towing was the same as in regular trawling but the towing depth was adjusted by changing warp length or ship speed. The average towing time was about 45 minutes at a ship speed of 1.7 knots. The catch per tow averaged around 1 ton. Both the Russians and the Japanese have found the best fishing in January.

The Nippon Suisan Company, a large Japanese fishing firm, recently sent its 3,600-ton stern trawler, *Aso Maru*, to the Antarctic Ocean to fish commercially. The reported catch was 1,600 tons of krill. The company is now working on product development.

Product processing and utilization problems remain. It has already been learned that krill frozen immediately after capture tends to lose much of its nutritive body fluids when thawed. A better method is to boil the krill before freezing. As for utilization, the Russians have developed a product called "krill paste" which is being marketed in frozen blocks. This paste reportedly has a very fine flavor and the odor of shrimp, and is a product very well accepted by consumers for flavoring salads or mixing with butter or cheese. The Russians are also using the krill to make meal as well as a product called "pressed cake."

The Japanese have sent samples of krill to various laboratories to work on product development. As of now, some use has been made of krill as soup stock, or as "tsukudani," where krill is cooked in soy sauce. Work is proceeding on using krill to manufacture "FPC," or protein concentrates. JAMARC is interested in developing products that would have universal appeal rather than something that would be suitable to the Japanese palate alone.

Undoubtedly, krill will figure more importantly in the future as the problem of feeding the growing world population becomes more critical. Several other nations have indicated interest in the krill. West Germany and Norway are reported planning to dispatch survey ships to the Antarctic for the coming krill season.

UNUSUAL ABUNDANCE OF EEL ("UNAGI") ELVERS

Although the most recent statistics are unavailable, I have heard that in 1970, the annual consumption of "unagi" in Japan amounted to around 30,000 tons. Of this amount, Japan was able to produce 20,000 tons, and the remainder had to be imported. Furthermore, it was reported that of the 20,000 tons produced domestically, 17,000 tons comprised "cultured" eels, and 3,000 tons were fish taken in the wild. The remainder came from Korea and Taiwan. Eels are one of the favorite food fishes in Japan, and are served at specialty restaurants. Today, the Japanese are often heard to say that "unagi" dishes are now so expensive that they can rarely afford to enjoy them. The reasons for the high prices are the scarcity of "wild" eels, the high cost of "culturing" (in effect, it is "rearing" rather than "culturing"), and the need to import elvers for rearing.

In recent years Japan has been depending more and more on the so-called cultured eels where elvers are reared to marketable size. Because of the shortage of elvers in Japan, they had to be imported from such countries as France, Spain, South Korea, and Indonesia at very high prices. During my visit to an "eel culturing cooperative" in Hamamatsu, Shizuoka Prefecture, I was told that prices of elvers reached a record high of 400,000-500,000 yen/kg (US$627-784/lb) a few years ago because of general scarcity. In February 1975, during my visit, prices had fallen to 15,000 yen/kg (US$24/lb) and even lower in some places. The reason for this great decrease in elver prices was the unusually high abundance of elvers in Japanese coastal waters this year.

For the first time in 10 years, elvers appeared in great quantities off the Pacific coast extending from around Shikoku Island to the vicinity of Shizuoka in Honshu. In Shizuoka, the elvers first made their appearance around December 1974, about a month ahead of the usual elver season, which extends into March. At Lake Hamano, about 50 km west of Shizuoka City, fishermen were busily harvesting elvers with set nets ("teichaku ami") placed just inside of the lake entrance. According to the officials of the cooperative, fishing is done at night, as the incoming currents sweep the elvers into the large net. The cod end is lifted to remove elvers at hourly intervals. No lights are used.

After some initial mortality the elvers apparently do quite well, with about an 80 percent survival. They are taken to the rearing areas where they are held in cages, 2 kg of elvers to a cage, suspended in freshwater. These transparent elvers, 5-7 cm in length, are said to be about a year old when captured. They change color in a few weeks, becoming quite dark and nearly doubling in size. As the elvers grow they are transferred to larger rearing ponds and fed regularly on specially prepared powdered food. Adults are fed mackerel and other fish.

During winter, the rearing ponds are heated to about 25°C to induce feeding and rapid growth. The water is aerated by stirring with a paddle-wheel contraption. The elvers increase in length to 20-30 cm in 2 years. (According to one official, this amount of growth requires 10 years in nature.) The eels are marketed soon thereafter. When asked about spawning grounds, the official replied that these eels are believed to be spawning in the vicinity of Taiwan, but that there may be some spawning also off southern Japan, with elvers being swept north along the Kuroshio. The low prices for elvers may not affect the retail prices of eels too greatly since rearing costs continue to be very high, particularly the cost of fuel oil necessary to heat the water in the rearing ponds during winter. (Author's note—Many of the details given in this section were recorded during my interview with the cooperative official, but they are unverified and may contain errors in detail.)

PROBLEMS WITH SOVIET FISHERMEN

On 17 February I saw a television newscast showing Japanese coastal fishermen demonstrating in large numbers, asking the Government to intervene in their behalf in regard to their problems with Soviet fishermen. The news report indicated that Soviet trawlers off Kinkazan (northeastern Japan) were damaging nets used by Japanese coastal fishermen, thereby causing painful financial losses. Later, I learned that 30-40 Soviet trawlers were fishing around huge motherships of 20,000-30,000 tons just over 3 miles from the Japanese coast. By mid-February, the fleet had moved southward to off Choshi (approximately the latitude of Tokyo), where they were harvesting mackerel by stern trawling. Japanese Coast Guard helicopter crews reported sighting several fleets of trawlers just outside of the 3-mile zone. They reported that mackerel fishing was being done by stern trawling, and that the catches were being processed on board the motherships (canning factories). Heads, tails, and entrails of mackerel were being tossed overboard.

The Japanese fishermen reported that their small vessels (30 tons in size) are absolutely no match for the Soviet trawlers, which are about 400 tons in size. They have already sustained heavy damages to fishing gear. In December, Japanese fishermen reported suffering $121,000 in damages to nets off Iwate Prefecture. This year, they reported damages totaling $241,000 in 12 separate incidents. Off Choshi, the damages in two reported incidents totaled $55,000. There were other reported incidents, bringing total losses to many thousands of dollars.

An even worse fear loomed. Mackerel spawning off Shizuoka was coming up soon and the Japanese felt certain that the Soviet fleet would move southwest to harvest the spawning fish. If they did, the coastal fishermen were afraid that the mackerel resource would be decimated. They were appealing to the Government to come to their assistance, and if possible, declare a 12-mile fishery zone in Japan.

Japanese fishermen had complained to the Soviet Embassy in Tokyo with no results. But news reports indicated that the Japanese Foreign Ministry was to meet with the Russians to work out an amicable solution.

MISCELLANEOUS

Sardines

Sardine catches began to increase in the spring of 1973, and the year's catch amounted to 200,000 metric tons. The catch was reported to be even better in 1974, when an estimated 500,000 metric tons were anticipated. In February 1975, sardines were reportedly being taken in such large quantities that they were being given away at some of the northern ports.

Building Boom Continues for Large Skipjack Tuna Vessels

In February, more than 10 large (499-ton) skipjack tuna fishing vessels were being constructed, mostly under order from Mie Prefecture. This trend toward larger vessels is due to the greater distance to fishing grounds and the need for vessels of larger carrying capacity. A 434-ton vessel reportedly can carry about 300 tons of fish; a 499-ton vessel should be able to carry 400 tons. Such large vessels started fishing around September 1974, but their efficiency is not yet clearly determined. The opinion being expressed now is that such large vessels will do very well during good seasons such as 1973 but poorly during such years as 1974, when fishing was relatively poor and bait mortality high.

Roback[2] Automatic Fishing Machines

According to officials of Iwatani & Co., sales agent for the Roback automatic fishing machines, there are now 25 Roback fishing machines installed on Australian vessels, 4 in Hawaii, 15 on the west coast, and about 600 machines on Japanese vessels. The company has received inquiries from Spain and France. An order for machines has come from Canada. An albacore vessel being built in Seattle apparently will install 10 machines and thus greatly automate its fishing capabilities.

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[2] Reference to commercial products does not imply endorsement by the National Marine Fisheries Service, NOAA.

MFR Paper 1165. From Marine Fisheries Review, *Vol. 37, No. 11, November 1975. Copies of this paper, in limited numbers, are available from D825, Technical Information Division, Environmental Science Information Center, NOAA, Washington, DC 20235. Copies of* Marine Fisheries Review *are available from the Superintendent of Documents, U.S. Government Printing Office, Washington, DC 20402 for $1.10 each.*

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(4)　ホノルル水産研究所の竿釣生餌輸送試験結果

米国NMFS，南西漁業センターホノルル水産研究所　Tamio Otsu

昨年のマグロ協議会で，私は，これからのハワイのカツオ漁業の発展を助ける一つの方法として，カリフォルニヤからハワイへ生餌を輸送する計画について報告いたしました。ハワイのカツオ漁業は，ハワイで生産できる餌魚の量が限られているため，その発展が阻まれてきました。ハワイでは，ネフーとよばれる小さなカタクチイワシの仲間が生餌として，使われていますが，量に限りがあり，毎年5月から9月の盛漁期に餌が不足する傾向があります。

その結果，漁業に要する時間全体の約 40％にも及ぶ時間が，餌とりに使われることになります。餌とりの時間を少くして，釣る方にふりむけることが出来れば，その分だけ漁獲をあげ得ることになります。さらに，この生餌供給の問題が解決されれば，新しい船隊がハワイの船隊に加わることが出来，カツオ漁業の発展が可能となるはずです。

私たちは，ハワイ漁業を振興させる方策について，いろいろと検討した末，カリフォルニヤからの生餌輸送が，恐らく最も現実的な解決策であろうという結論となりました。カリフォルニヤには Engraulis mordax と言うカタクチイワシの大きな資源があります。この資源は年間を通じて，利用できます。もし，このカタクチをハワイへ定期的に，また適当な値段で，輸送することが出来れば，ハワイのネフーの不足を補ない，前に申しましたように，ハワイのカツオ漁業の発展に役立つ筈であります。この試験によって開発された技術は，また，竿釣に適した餌魚の量が不足しているため漁業の発展をさまたげられている，他の西部及び中部太平洋の地域にも適用出来ることになるわけであります。

生餌輸送方法

我われはまず，生餌の輸送タンクとして，約19キロリットルの容量を持つ，アメリカ空軍の使い古しの燃料補給タンクトレーラーこのタイプのハイウエータンカーは，石油会社がガソリンスタンドにガソリンを運ぶのに使っているものです ー を利用することにしました。我われは，これを手に入れてから，生餌の輸送のために，水の循環を開放式と閉鎖式の両方出来るように改造しました。

また，ハイウエーをタンクトレーラーを曳行するために，やはり使い古しのトラクターを手に入れました。こういう着想を持ったのは，MATSON 海運会社が運行している新車積みの貨物船による輸送を考えたからであります。

これらの新鋭貨物船のうち，2隻が，現在カリフォルニヤとハワイ間に就航しており，ホノルルとロングビーチの間を10日間で往復する航海をしております。二つの港の走行に要する日数は，わずか4日間です。生餌はロングビーチの港で輸送タンクに積みこまれます。それから貨物船の場所まで運ばれる間，輸送タンク内は閉鎖循環方式で操作されます。船に積まれてから，航行中は，タンクは開放式にされ，水は船の消火栓から供給されます。タンクからの排水は船の外に流されます。こうして，4日の後，タンクはホノルルに着きますが，到着と同時に閉鎖式にきりかえられます。そこで，トラクターが船にあがり，輸送タンクをひき出して，Kewalo Basinにある我われの研究施設まで輸送します。Kewalo は，また，カツオ船の錨地でもあります。

昨年，我われはこの試験計画のために数人を割当て，試験を実施しました。現在までの結果は，完全に成功という所までは行っていませんが，非常に多くのことを学ぶことが出来ました。今日は，そのうちの若干のことについてお話したいと思います。

カタクチイワシの利用度

先ず第一に，私達が知ったことは，カタクチイワシがカリフォルニヤでは周年利用出来るという事でした。生餌の供給基地としては，貨物船のターミナルであるという理由から，ロングビーチをえらびました。ロングビーチには，この地域のスポーツフイッシャーマンやビンナガ釣りの漁業者にカタクチイワシを供給する餌売業者がいます。彼は，我われの生餌輸送計画に興味を持ち，カタクチを必要なだけ我われに供給することに同意してくれました。

カタクチ輸送試験

はじめは生餌輸送用にタンクを改造してから，これをカリフォルニヤへ送り，カタクチイワシを少しだけ積んでハワイに送り返しました。この最初の輸送試験では，生餌の死亡率は約50％でした。このように高い死亡率となった原因としては，我われはタンクが死んだ魚を除去する構造になっていなかったこと，および，蓄養期間が短かく，よく馴致されていない〝green fish〟を運んだことにあると考えました。

この試験の結果から，我われはタンクの改造を進め，死亡魚を除くためのサイフォンをとりつけました。ところが次の輸送試験では，このサイフォンは死んだ魚ばかりでなく，大量の生きた魚ま

ですい出してしまう結果となりました。それこれの理由で，また死亡率は高く，50－60％に達しました。サイフォンの構造に大幅な改良が必要なことがはっきりしたわけです。そこでサイフォン系統の改良に的をしぼってタンクの改造を進めました。

ロングビーチでのテストでは，死んだ魚はタンクの底に沈んだ際にサイフォンで除去され，上に浮んだものは，オーバーフローにより除かれるようになりました。しかし，実際の輸送試験では，死亡魚が排水口につまってしまうという困難やその他予期しなかった問題にいくつも遭遇しました。

我われの行った最後の改造は，安全弁をつけた粗い目合のスクリーンを排水口のあたりにつけることでした。安全弁はゴムのスカートであり，スクリーンの目が完全につまった時にだけ全部の魚を通すように設計されています。これらのスクリーンは，タンクの上面のオーバーフローのところにとりつけられましたが，非常に能率のよいことが分りました。同時に，改良されたサイフォンがタンクの底から老廃物を除くために作動されました。

残念ながら，このサイフォンは，最後の輸送試験できかいのこしようがおき，積んだ魚の大部分が失われました。

これらの経験から，今後改善すべき点は明らかになったと思われます。すなわち，タンクの上面にとりつけて成功したのと同様のスクリーンをタンクの底の排水口の上にもとりつけることであります。これによって死魚が排水口につまることはなくなるはずです。もしつまった場合は，安全弁が作動して緊急事態が回避されるでしょう。

この装置は，死んだ魚を外へ出すよりもむしろ残すように設計されます。しかし，タンクの水はずっとながれ出るのではいぶつがたまることが防げると思います。今後の輸送計画は，タンクの全ての排水口に新しいスクリーン装置をつけて，実施されるはずであります。

餌魚の馴致

昨年，マグロ協議会に出席した後，私は網代，宇佐美，別府，佐世保などいくつかの餌場を訪ねました。どの餌場でも，私が関係者の方達との話を通じて，学んだことは，生餌をどのように注意深く扱っても，漁獲後の初期の死亡率は約 30％である，ということでした。

餌魚は，生簀に馴致されるある期間の後，だんだん強くなるようであり，実際，南方漁場で使われる生餌のあるものは，漁獲後，2ケ月も生簀で蓄養され，給餌されるということであります。生餌をかなり長距離に運ぶためには，その前に，生簀で馴致することが最も重要であるように思われます。

このことは，昨年6月ホノルルで開かれました餌魚に関する研究集会でも，論議されました。出席者の一致した意見として，我われも，また生餌を輸送タンクで運ぶ前に，これを馴致する必要がある，ということでした。馴致期間中に弱い魚を除くようにすれば，死亡率を最低にすることが出来るだろうと考えられます。しかし，アメリカの餌魚業者は，日本の業者のように，馴致された餌魚を売らないので，この実験は，我われ自身の手でやることにしました。そこで，数ケ月前に，我われはロングビーチでコーストガードから，港の若干の場所を借りまして，餌魚馴致の目的で二つ

のプラスチックタンクを設置しました。この二つのタンクは，直径が7.2m（24ft），深さが1.2m（4ft）で，少くとも900kg（2,000ポンド）のカタクチを収容できます。実験の内容は，餌魚業者から買ったカタクチを，二つのタンクに入れ，約1週間畜養した後，これらの生餌を輸送タンクでハワイに送るということでありました。

タンクの生餌輸送容量

ロングビーチで馴致されたカタクチを使って，いくつかの実験が行われました。これらの実験は，我われの19ギロリットル（5,000ガロン）の輸送タンクについて，最適の生餌収容量はどれ位かを知るのが目的でした。4日間をこえる期間，これはロングビーチからホノルルまでの輸送期間を考えてですが，この期間にあたり，いくつかの異なった収容密度について実験を行ないました。実験の結果を要約しますと，3.78リットルの水（1ガロン）に対して，カタクチを約0.15kg（0.34ポンド）の収容密度までは，4日間の生残率は約70％でした。この収容密度を越えると，過密の効果は明らかとなり，生残曲線は低下の傾向を示しました。

このように，輸送最適密度は，1ガロンの水に対して0.34ポンド，いいかえれば我われの輸送タンクでは1,700ポンド（約770kg）という事になります。4日の後の生残魚は1,100ポンド（500kg）となるでしょう。我われの輸送タンクを使って，これだけの量のカタクチをハワイまで，よい状態で運ぶ事は可能と考えてよいと思います。船上の給水により，充分な酸素供給が出来ますし，ロングビーチとホノルル間の水温変化は大した問題ではありません。

将来の計画

現在までのところ，我われは1,100ポンドのカタクチを1回のタンク輸送でホノルルまで運ぶことが可能なことを示しました。我われの経済的な分析によれば，タンク輸送にかかる一切の経費を考慮に入れた場合，この生餌輸送事業は，もし1回の輸送で1,100ポンドのカタクチを運ぶことが出来れば，経済的にひきあうものとなるようです。カタクチを1ポンド約2ドルで漁業者に売ることにすれば，この生餌輸送は経営的に成立つことになります。

もちろん，一つの輸送タンクでは不充分です。回転を考えて，恐らく，6つか8つのタンクが必要でしよう。それによって，カリフォルニヤからハワイまで特に生餌の必要な夏の時期に，3つか4つのタンクの生餌がいつも供給されることになりましよう。

我われは，この数ケ月の間に，ハワイの漁業者がカタクチをよろこんで買うこと，1ポンド約2ドルというねだんは彼等に充分受け入れられるものであることをたしかめました。また，彼等がカリフォルニヤのカタクチを，ハワイ水域のカツオ釣の餌魚として非常にすぐれていると思っている事が分りました。しかし，予想される重大な問題は，漁業者が体長10cmをこえる大きなカタクチは生餌として大きすぎるとして，買いたくないと言うのではないかということであります。理想的なサイズのカタクチを運ぶということはむずかしい問題です。

一方，大きなカタクチは，最初の餌づけ，すなわち，カツオを船にひきつけるためにすぐれてい

るということから，用いられてきました。しかし，これらの大きなカタクチは釣りがつづけられている間，船のトモにカツオをひきつけておくためには，小さなネフーより劣っている事が分っています。

さて，我われはこの試験を今後もつづけて行くことを計画しております。もう1ー2回の追加輸送試験によって，生餌輸送計画を本格的な事業とすることが出来るかどうかの答えが得られるだろうと期待しております。

RESULTS OF TUNA LIVE BAIT TRANSPORTING EXPERIMENTS OF THE HONOLULU LABORATORY[1]

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INTRODUCTION

At the Japan Tuna Conference last February, I reported on the plans of the Honolulu Laboratory to assist the Hawaiian skipjack tuna fishery by transporting baitfish from California to Hawaii. The Hawaiian skipjack tuna fishery is limited in its growth and development because of the scarcity of naturally occurring baitfish in Hawaii. The Hawaiian baitfish, a small anchovy called nehu, Stolephorus purpureus, is limited in supply, and tends to be scarce during the peak skipjack tuna fishing season between May and September. Consequently, a large proportion of the fishermen's time, perhaps up to 40%, is spent in trying to catch sufficient bait to go fishing for skipjack tuna. If the bait-catching time can be reduced and if the time saved can be more profitably applied to skipjack tuna fishing, then the catches of skipjack should increase proportionately. Furthermore, if availability of baitfish is no longer a problem, then it is probable that new fishing vessels will join the Hawaiian fleet and the skipjack tuna fishery is bound to grow.

After studying the various options available to assist the Hawaiian fishery, we decided upon the transporting of baitfish from California to Hawaii as being perhaps the most practical and most direct approach to take. In California, there is a large resource of northern anchovy, Engraulis mordax, available throughout the year. If this fish can be transported to Hawaii on a regularly scheduled basis, and at reasonable cost, then it should serve to augment the local nehu supply and enable considerable development of the Hawaiian skipjack fishery.

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[1] Prepared for presentation at the 1975 Japan Tuna Research Conference, Shimizu, Japan, February 4-6, 1975. This presentation will be given in the Japanese language.

NOTE: Units of measurements throughout the Japanese version will be in the metric system.

The techniques developed in this experiment should also be applicable to other areas of the central and western Pacific where fishery development is hampered by the lack of sufficient amounts of suitable baitfish.

BAIT-TRANSPORT METHOD

We decided to use a surplus military aircraft refueling tank-trailer (the type of highway tanker the oil companies use to deliver gasoline to the retail outlets) of 5,000-gallon capacity as our baitfish-transport tank. We obtained a surplus tank and modified it for carrying fish in both open- and closed-circulation modes. A surplus tractor was also obtained for towing the tank-trailer on the highway. The concept is dependent upon the new "roll on/roll off" freighters operated by Matson Navigation Co.

These modern freighters, two of which now operate between California and Hawaii, make a round trip between Honolulu and Long Beach in 10 days. It requires only 4 days to transit between Hawaii and Long Beach. The baitfish is loaded into the tank at Long Beach Harbor. A self-contained, life-support system operates the tank in a closed-circulation system as it is towed from the bait pier to the freighter terminal and aboard the ship. During the ocean crossing, the tank operates in a flow-through system with water supplied by the ship's fire hydrant system. Discharge from the tank is off the side of the ship.

Four days later, the tank arrives in Honolulu where it is switched to the closed-circulation system. A tractor is driven on the ship to take the tank-trailer in tow back to our Laboratory's facility at Kewalo Basin. Kewalo is also where the Hawaiian skipjack tuna fleet is berthed.

During the last year we assigned a few men to this project, and although the results to date have not been overwhelmingly successful, we did learn a lot, and I would like to report some of the results to you today.

AVAILABILITY OF NORTHERN ANCHOVY

First of all, we learned that anchovy are available in California throughout the year. We selected Long Beach Harbor as our bait supply point because this is the California terminal of the roll on/roll off freighters. There is a bait dealer in Long Beach who supplies anchovy to sport fishermen and to albacore fishermen in the area. He is interested in our bait-transport project and has agreed to supply us with the necessary amounts of anchovy.

TRIAL SHIPMENTS OF ANCHOVY

Initially, after modifying the fuel tank to carry fish, we sent the tank to California and returned it to Hawaii with a rather small load of anchovy. The mortality on the first shipment was about 50%, and we attributed this high mortality to the fact that the tank was not provided with a mechanism to remove dead fish and also because we were carrying "green fish" (fish that had just been caught by the bait fishermen and not acclimatized in captivity).

Following this experiment, we proceeded to modify the tank by installing a "siphon system" to discharge dead fish. During the next trial shipment the "siphon system" not only discharged dead fish but also a large number of live fish as well. Again, from a combination of factors, the mortality was high, at around 50% to 60%. It was obvious that the "siphon system" needed considerable improvement.

The modification of the tank continued to the point where a more satisfactory "siphon system" was developed. Tests in Long Beach showed that dead fish were being discharged as they sank to the bottom of the tank and those that floated above were being discharged by the overflow system. However, in actual shipment, we continued to encounter difficulties from dead fish clogging the discharge outlets and other unexpected problems.

Our latest modification was the installation of very large area screens with "safety valves" (these are rubber skirts) which were designed to pass whole fish only in the event that these screens should become completely clogged. These screens were tried in the top overflow system and found to work very efficiently. At the same time, an improved version of the "siphon system" was used to remove metabolites and decay products from the tank's bottom. Unfortunately, this bottom system suffered a mechanical failure during the last shipment and most of the load was lost. The remedy now appears obvious: Large-area screens similar to the successful new top screens should also be installed at the bottom of the tank over the bottom discharge outlets. With such a system,clogging should not occur. If it does, the "safety valve" feature will allow relief of pressure. The system will be designed to retain the dead fish rather than pass them out; however, the screens will be positioned so that water coming in contact with either floating or sunken dead fish will already be on its way out of the tank. This will prevent any buildup of decay products. Future shipments will be made using the new screening devices at all outlets, both top and bottom.

ACCLIMATIZATION OF BAITFISH

Last year, following the Tuna Conference, I visited several baiting areas in Ajiro, Usami, Beppu and Sasebo. In each area where I visited and talked with persons involved in the bait fisheries, I learned that the Japanese anchovy suffer an initial mortality of about 30% after capture, regardless of how carefully the baitfish are handled. It seems that the baitfish get stronger and stronger after a period of acclimatization in the ikesu. In fact, some of the bait being taken to the southern water skipjack fishery (Nanpo Gyojyo) are anchovy that had been held in the ikesu and fed for a period of as long as 2 months after capture. It seems of utmost importance that the baitfish are acclimatized in the ikesu before they are transported any distance.

This fact was discussed at the Tuna Baitfish Workshop that was held in Honolulu this past June. There was general agreement among the participants that we, too, should acclimatize the anchovy before they are shipped in our transport tank. It was felt that this would minimize mortality since we would then have weeded out the weaker baitfish during the period of acclimatization. However, since American bait dealers do not provide acclimatized bait as do the Japanese bait dealers, we decided to handle this procedure ourselves. Thus, a few months ago, we borrowed some pier space from the U.S. Coast Guard in Long Beach Harbor, and set up two plastic tanks for the purpose of acclimatizing baitfish. The two tanks, 24-ft in diameter and 4-ft deep, could together hold at least 2,000 pounds of anchovy. Our experimental procedure was to receive the anchovy from the bait dealer, put them into the two holding tanks, keep and feed the fish for about a week, and ship these fish back to Hawaii in the transport tank.

CARRYING CAPACITY OF THE TANKS

Several experiments were conducted in Long Beach using acclimatized anchovy. These experiments were designed to show the optimum carrying capacity of our 5,000-gallon transport tank. Various densities were tested over 4-day periods, simulating the time required to cross the ocean from Long Beach to Honolulu. In summary, the tests showed that survival rate was about 70% during the 4 days for densities up to around 0.34 pound of fish per gallon of water. Beyond this density, the effect of overcrowding became apparent and the survival curve trended downward. Thus, the optimum carrying capacity appears to be around 0.34 pound per gallon, or 1,700 pounds of anchovy in this particular tank. The survival after 4 days would result in a net load of 1,100 pounds. There is every reason to believe that we can ship this amount of fish to Hawaii in good condition. The water circulation on the ship provides sufficient oxygenation, and temperature changes between Long Beach and Honolulu do not pose a serious problem.

FUTURE PLANS

As of today we have yet to demonstrate that 1,100 pounds of anchovy can be carried to Hawaii in one shipment of the tank. According to our economic analysis, taking into consideration all the costs involved in shipping a tankful of bait to Hawaii, this venture will be cost-effective if we can deliver 1,100 pounds of anchovy in a single shipment. By selling the anchovy for about $2 per pound to the fishermen, the bait shipment can be made into a self-paying venture. Of course, one tank is not sufficient. We would need perhaps 6 or 8 such tanks...perhaps 3 or 4 loaded tanks coming into Hawaii at any one time; and 3 or 4 empty tanks moving out towards California, thus having a continuous flow of baitfish from California to Hawaii, particularly during the summer months.

We have already determined during the last few months that the Hawaiian fishermen are willing to pay for anchovy, and a cost of approximately $2 per pound is quite acceptable to them. We have also learned that the fishermen find anchovy to be an excellent baitfish for skipjack in Hawaiian waters. However, one complaint which may turn out to be quite serious is the fact that our fishermen find any anchovy larger than about 10 cm to be too large as live bait and may be unwilling to pay for such over-sized fish. To deliver anchovy of ideal bait sizes may be a problem. On the other hand, large anchovy were used for skipjack fishing and were found to be excellent for initial chumming...that is, to attract the skipjack to the vessel. These large fish, however, were found to be inferior to the much smaller nehu for holding the skipjack at the stern of the vessel while fishing was in progress.

Our plan is to continue with our experiments. We hope that in one or two additional trial shipments we shall be able to have the answer as to whether or not to proceed with a full-scale commercial baitfish transport program.

Distribution and Differentiation of Populations of Dolphins of the Genus *Stenella* in the Eastern Tropical Pacific[1]

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PERRIN, W. F. 1975. Distribution and differentiation of populations of dolphins of the genus *Stenella* in the eastern tropical Pacific. J. Fish. Res. Board Can. 32: 1059–1067.

There are at least two races of spotted dolphin, *Stenella attenuata*, in the eastern Pacific, based on length, color pattern, and skeletal differences. The coastal form is provisionally called *S. attenuata graffmani*. The offshore form is distinct from a third, Hawaiian race. Likewise, at least three unnamed races of spinner dolphin, *S. longirostris*, occur in the eastern Pacific. Length, shape of adult male, color pattern, and cranial differences are used to distinguish a Costa Rican, an eastern, and a whitebelly race. An Hawaiian race is distinct from these. A distributional break may indicate two stocks of the striped dolphin, *S. coeruleoalba*.

PERRIN, W. F. 1975. Distribution and differentiation of populations of dolphins of the genus *Stenella* in the eastern tropical Pacific. J. Fish. Res. Board Can. 32: 1059–1067

Il existe au moins deux races de *Stenella attenuata* dans le Pacifique oriental, se distinguant par la longueur, le motif de coloration et le squelette. Nous nommons provisoirement la forme côtière *S. attenuata graffmani*. La forme du large est distincte d'une troisième, la race hawaïenne. Semblablement, au moins trois races sans noms de *S. longirostris* se rencontrent dans le Pacifique oriental. La longueur, la forme des mâles adultes, le motif de coloration et les différences craniennes servent à distinguer une race de Costa Rica, une race orientale et une race à ventre blanc. Une race hawaïenne est différente de celles-ci. Une discontinuité dans la répartition peut indiquer l'existence de deux stocks de *S. coeruleoalba*.

Accepted March 14, 1975 Accepté le 14 mars 1975

THE purse seine fishery for tuna in the eastern tropical Pacific employs three species of *Stenella* (Perrin 1968, 1969; NOAA 1972). The purpose of this paper is to describe the distribution of the subpopulations of these three species and the grounds for separating them.

The involved species of dolphin are *Stenella attenuata* (Gray, 1846), called "spotted porpoise" by the American tuna fishermen, *S. longirostris* (Gray, 1828), called "spinner porpoise," and *S. coeruleoalba* (Meyen, 1833), called "streaker porpoise." The taxonomy of the genus is unsettled, and the nomenclature used here is provisional. *Stenella attenuata* is the most important of the three species to the fishery (Table 1). *Stenella longirostris* is next most important. Only a very few net sets are known to have been made on *S. coeruleoalba*. Other cetaceans involved in the fishery are the delphinids *Delphinus delphis* L., *Tursiops* sp., *Lagenodelphis hosei* Fraser, 1956, and *Steno bredanensis* (Lesson, 1828), the latter three to very minor extent.

Materials and Methods

Most of the distribution data and the specimens used for morphological studies were collected by scientific observers aboard commercial tuna seiners during the period 1968–74. I also surveyed available U.S. museum collections and the literature. Complete details concerning the specimens and methods used in the analyses of morphology have been previously presented (Perrin 1972a, 1973).

In tagging dolphins to delineate their ranges and migrations, several tagging methods and types of tags were used. Animals were tagged on the deck after being extricated from the net or separated from the catch of tuna, in the net during the "backing down" rescue operation (Perrin 1969; Coe and Sousa 1972), or as they rode the bow-wave of the vessel. Dart-type spaghetti tags of two types were used. Initially, an all-plastic tag was used (Mather 1963). Since 1971, a tag with a metal dart (Mather 1963) has been used. Animals on the deck or in the net were tagged with a short wand. Bow-riding animals were tagged with a long wand with a quick-release head (Beckett 1968) or with a crossbow (Evans et al. 1972). Some

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[1] Prepared for the meeting of the "Subcommittee on Small Cetaceans, Scientific Committee, International Whaling Commission," held at Montreal, Quebec, Canada, April 1–11, 1974.

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TABLE 1. Observed net sets on delphinids by tuna purse seiners, 1971–74.

	Number of observed net sets (% of year's observed sets in parentheses)			
Stock	1971	1972	1973	1974[a]
Stenella attenuata	64 (94.1)	219 (90.5)	616 (81.5)	681 (84.4)
Coastal race	0	0	7 (1.0)	0
Offshore race	64 (94.1)	219 (90.5)	609 (80.6)	666 (82.5)
Unidentified to race	0	0	0	15 (1.9)
S. longirostris	40 (58.8)	138 (57.0)	311 (41.1)	313 (38.8)
Eastern race	28 (41.1)	70 (28.9)	147 (19.4)	286 (35.4)
Whitebelly race	12 (17.6)	28 (11.6)	43 (5.7)	49 (6.1)
Unidentified to race	11 (16.2)	6 (2.5)	117 (15.5)	1 (0.1)
S. coeruleoalba[b]	0	0	2 (0.3)	2 (0.2)
Delphinus delphis	2 (2.9)	26 (10.7)	97 (12.8)	110 (13.6)
Northern race[c]	0	0	15 (2.0)	0
Southern race[c]	2 (2.9)	26 (10.7)	82 (10.8)	110 (13.6)
Tursiops sp.[b]	3 (4.4)	7 (2.3)	5 (0.7)	34 (4.2)
Lagenodelphis hosei	1 (1.5)	0	0	0
Steno bredanensis	0	0	0	2 (0.2)
Total sets observed[d]	68	242	756	807

[a] Partial data, as of March 25, 1974.

[b] May be more than one stock.

[c] Races *fide* W. E. Evans personal communication.

[d] Do not equal sum of species totals; some sets are on mixed herds.

TABLE 2. Races of *Stenella attenuata* in eastern Pacific and Hawaiian waters. Length data previously unpublished; color pattern and skeleton data from Perrin (1972b). Sample sizes in parentheses.

	Adult length (see Fig. 2) (*cm*)			Skeleton		
Race	Males	Females	Adult color patterns	Adult condylobasal length (*mm*)	Adult tooth diameter (*mm*)	No. vertebrae
Coastal	203–257 (37)	184–227 (76)	Dorsal spotting light to heavy, but medium to heavy in most. Dorsoventral contrast low.	419–460 (18)	3.4–5.7 (9)	77–79 (9)
Offshore	179–224 (332)	167–206 (1042)	Dorsal spotting light to heavy, but medium to light in most. Far offshore (> 800 km) animals lightly spotted.	356–411 (68)	2.7–4.0 (65)	77–83 (61)
Hawaiian	182–202 (6)	189–203 (3)	Dorsal and ventral spotting so obscure as to appear absent. Adult resembles neonate of offshore race (Perrin 1970).	395–440 (12)	—	79 (2)

plastic dorsal-fin tags (Norris and Pryor 1970) were also used.

Species Accounts

Stenella attenuata — There are at least two races of spotted dolphin in the eastern Pacific. They differ in several features (Table 2). A coastal form is relatively large and robust, has heavy jaws and teeth, is heavily spotted, and is restricted to onshore waters from the Gulf of California to northern Peru (Fig. 1). An offshore race is relatively small and slender, has lightly built jaws and teeth, is spotted to varying degree, and occurs in offshore waters west to about 145°

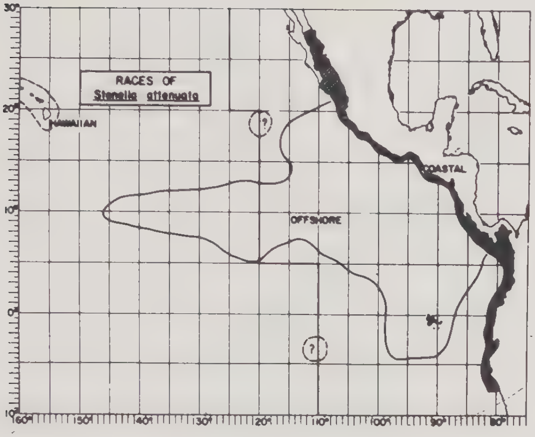

FIG. 1. Known ranges of races of *Stenella attenuata* in the eastern Pacific, based on collections and sightings by National Marine Fisheries Service observers aboard commercial tuna seiners and research vessels, museum collections and literature records. Boundaries are approximate only, and fluctuate seasonally and from year to year.

W long. The ranges of the two forms may overlap, or the boundary between them may move seasonally or from year to year. They have not been observed or captured together. In the central latitudes of the range the coastal form has been collected as far offshore as 50 km and the offshore form as far inshore as 20 km from the coast. The offshore form predominates in the fishery (Table 1). Another race inhabits the waters around Hawaii and may extend into the South Pacific and to the west. This form is also small and slender, but is less spotted.

The existence of two forms was first suspected upon comparison of a large series of skeletal specimens from the tuna fishery with the material available in museums, which consists mostly of animals harpooned on the coast and includes the type of *Stenella graffmani* (Lönnberg, 1934). Both series included obviously very young and very old individuals. The skulls in the coastal series were longer, broader, and had proportionately larger posttemporal fossae and teeth than those in the series from the tuna fishery (Perrin 1972a). The skulls of the two forms differ mainly in those features that have to do with feeding. The coastal form appears to be adapted to feeding on larger, more substantial prey than does the offshore form. The offshore form feeds primarily on epipelagic squids and fishes (Perrin et al. 1973). No data are available on the diet of the coastal form. The two series of specimens are statistically separable on the basis of aspects of the skull related to feeding (Perrin 1972a). The Hawaiian form is also separable on the basis of skull measurements. It has a longer, broader skull than does the offshore form but does not have the more massive feeding apparatus like that of the coastal race. Within the offshore race, an east–west cline may exist. Specimens from farthest west tend to be most Hawaiian-like.

The coastal form also has a larger, more massive postcranial skeleton than does the offshore form and, on the average, fewer vertebrae (Perrin 1972a). The range of vertebral counts for the coastal series is 77–79 (nine specimens), as opposed to 79–83 (48 specimens) for offshore animals taken from adjacent waters. Offshore animals from more than 800 km offshore tend again to have lower vertebral counts (77–82 in 13 specimens), supporting the concept of an east–west cline within the offshore race.

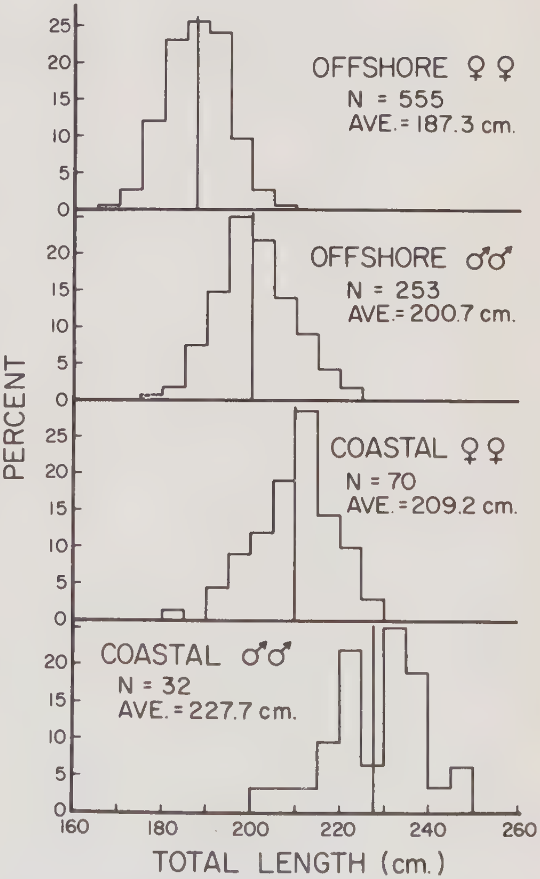

FIG. 2. Histograms of body lengths of spotted dolphins, *S. attenuata*, of two races, collected aboard tuna seiners in 1973. Specimens identified to race on the basis of locality of capture and range of lengths in sample.

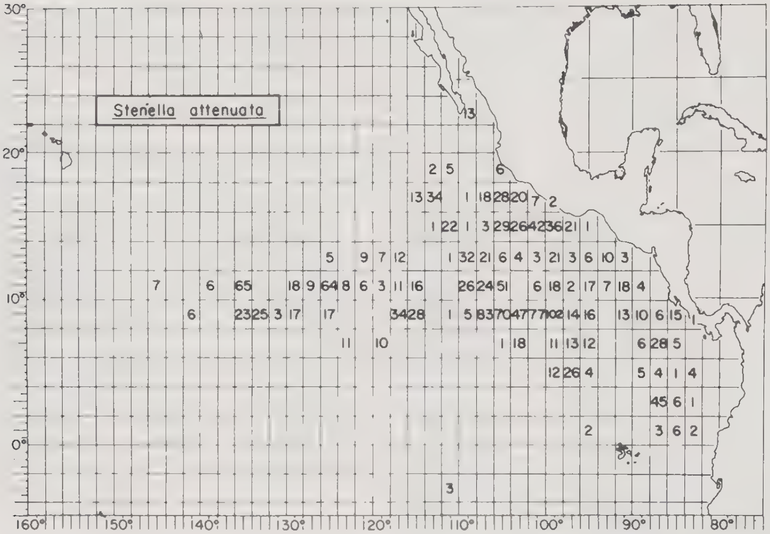
Stenella attenuata
13
2 5 6
13 34 1 18 28 20 7 2
1 22 1 3 29 26 42 36 21 1
5 9 7 12 1 32 21 6 4 3 21 3 6 10 3
7 6 65 18 9 64 8 6 3 11 16 26 24 51 6 18 2 17 7 18 4
6 23 25 3 17 17 34 28 1 5 83 70 47 77 102 14 16 13 10 6 15 1
11 10 1 18 11 13 12 6 28 5
12 26 4 5 4 1 4
45 6 1
2 3 6 2
3
30°
20°
10°
0°
160°
150°
140°
130°
120°
110°
100°
90°
80°

FIG. 3. Numbers of spotted dolphins, *S. attenuata*, tagged, 1969–74, by 2-degree square.

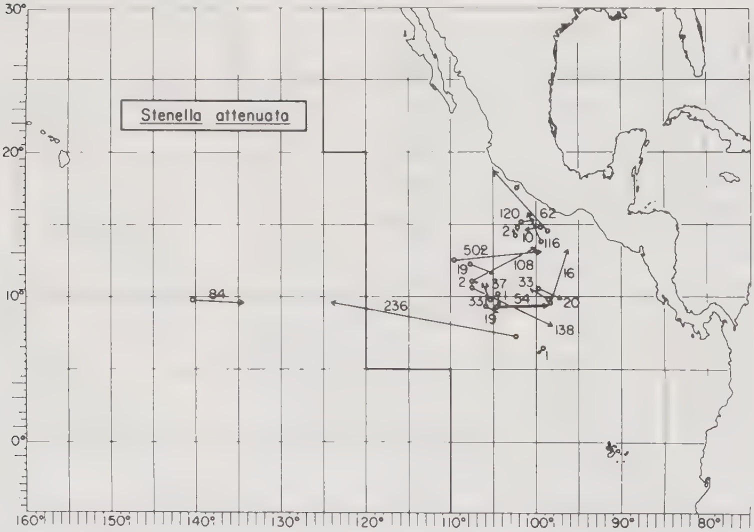
Stenella attenuata
84
236
120
62
28
10
116
502
19
108
16
2
37
33
33
54
20
19
138
1
30°
20°
10°
0°
160°
150°
140°
130°
120°
110°
100°
90°
80°

FIG. 4. Net movements of recovered tagged spotted dolphins, *S. attenuata*, with days at liberty.

Recent length data from the fishery also support the concept of two races in the eastern Pacific. Several samples of animals taken in 1973 from within 30 km of the coast of Costa Rica were clearly from a different population than samples taken from more offshore waters throughout the range (Fig. 2). The coastal adult females (those with ovarian scars) were on the average about 22 cm longer than the offshore females. The coastal adult males (those with testes weighing more than 200 g, the smallest size at which sperm has been found in the epididymis) were about 27 cm longer than the offshore males. Calculating from a length–weight relationship (unpublished data), this amounts to an average weight difference in adult males of about 35 kg (115 vs. 80 kg).

We have tagged 11 coastal and 1716 offshore spotted dolphins (Fig. 3), and recovered 24 tagged offshore animals from known locations (Fig. 4). Time at liberty ranged from 1.7 h to 502 days, and the distance from release point to recapture point ranged from 13 to 2415 km. These results show a great deal of east–west and north–south movement, evidence for extensive mixing within the eastern half of the supposed range of the offshore race. The degree of continuity between the eastern and far-western portions of the range is still unknown because of insufficient tag returns.

The three forms clearly deserve subspecific status (Perrin 1972a). Assignment of trinomials to the offshore and Hawaiian forms will have to wait until the taxonomy of the genus at the species level has been unraveled. Many of the holotypes in *Stenella* are from unknown localities. Relationships among spotted dolphins in the Atlantic and Pacific need to be examined. The name *graffmani*, however, clearly applies to the coastal form, and I therefore provisionally call the coastal form *S. attenuata graffmani*.

Stenella longirostris — There are at least three races of spinner dolphin in the eastern Pacific (Fig. 5), differing modally in several characters (Table 3). One that occurs very near the coast of Central America, referred to below as the "Costa Rican" form, is relatively long, slender, and gray. A second race, called "eastern spinner," occurs along the coast of Mexico and seaward about 800 km and is relatively short, slender, and gray. A third, called "whitebelly spinner", occurs in far offshore waters west to about 145° W long. and is relatively short, robust, and white below. A fourth form occurs in Hawaiian waters and possibly to the south and west and is relatively long, robust, and white below. The ranges of the eastern and whitebelly forms overlap (Fig. 5). In the area of overlap, the two forms are occasionally captured together. A few apparent intergrades have also been collected.

The eastern and whitebelly forms are both involved in the tuna fishery (Table 1). Existence of eastern and whitebelly races was discovered through field observations of color patterns. The Costa Rican–eastern and whitebelly–Hawaiian dichotomies were discovered while examining skeletal specimens.

As with *S. attenuata*, most of the geographical variation in the skull is in features functional in feeding (Perrin 1972a). The Costa Rican spinner has a proportionately longer, more lightly built rostrum and mandible than does the eastern

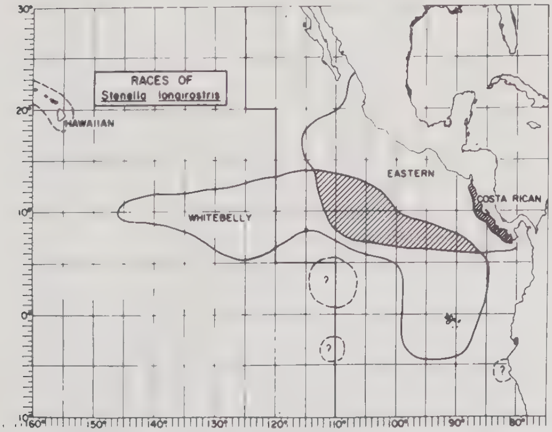

FIG. 5. Known ranges of races of *S. longirostris* in the eastern Pacific. Same data sources as Fig. 1. Boundaries are approximate only, and fluctuate seasonally and from year to year.

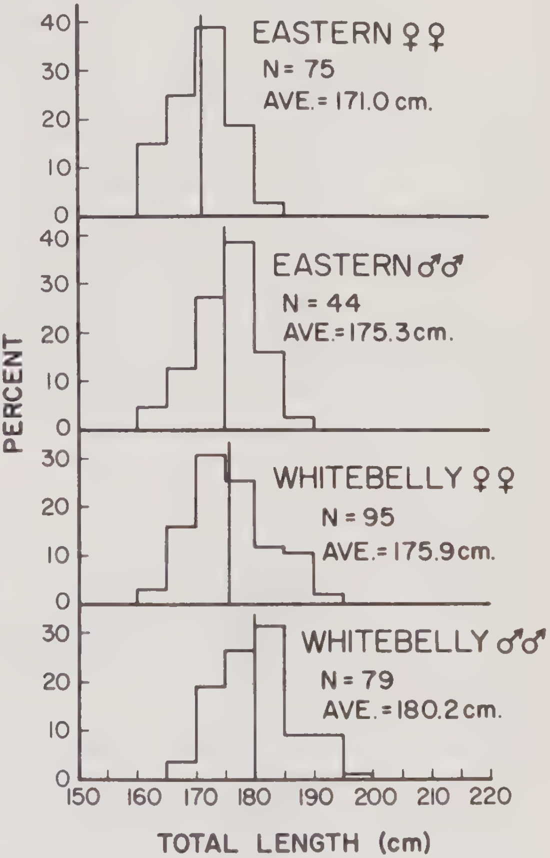

FIG. 6. Histograms of body lengths of spinner dolphins *S. longirostris*, of two races, collected aboard tuna seiners, 1968–73. Specimens identified to race on basis of locality of capture and color pattern.

TABLE 3. Races of *S. longirostris* in eastern Pacific and Hawaiian waters. Length data previously unpublished; other data from Perrin 1972a. Sample sizes in parentheses.

Race	Adult length (*cm*)		Shape of adult males		Color pattern (terminology of Perrin 1972b)	Skull	
	Males	Females	Dorsal fin	Ventral hump		Condylobasal length (*mm*)	Zygomatic width (*mm*)
Costa Rican	181–216 (2)	193–203 (3)	Canted to triangular	—	Poorly known, but like that of eastern.	416–437 (4)	149–152 (4)
Eastern	161–186 (44)	160–181 (75)	Canted to triangular	Medium to extreme	Dark dorsal field obscures cape and extends ventrad, leaving light areas in genital and axillary regions. Monotone effect.	351–407 (26)	139–153 (29)
Whitebelly	170–196 (79)	161–194 (95)	Triangular to falcate	Medium to slight	Dorsal field extends ventrad only to level of eye laterally and has irregular margin. Cape faintly visible through dorsal field. Bipartite effect.	365–419 (13)	145–158 (14)
Hawaiian	185 (1)	183–201 (2)	Falcate	Slight	Light dorsal field to level of eye, with smooth margin. Cape very obvious. Tripartite effect.	431–464 (10)	159–171 (10)

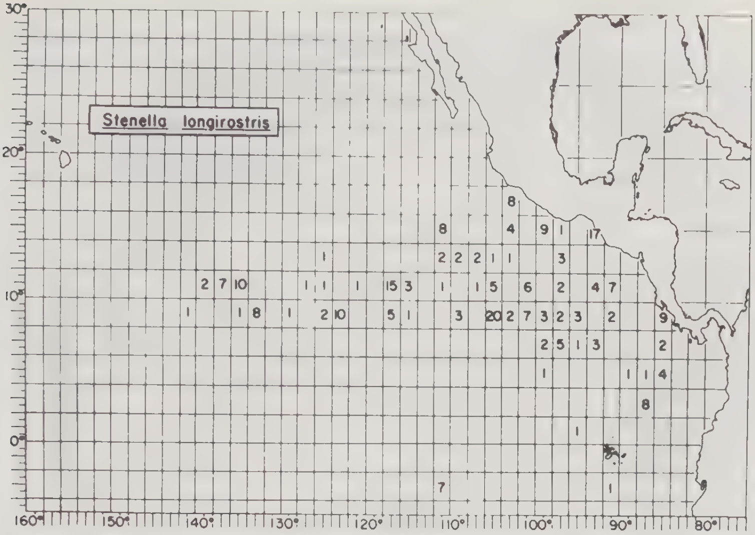

FIG. 7. Numbers of spinner dolphins, *S. longirostris*, tagged, 1969–74, by 2-degree square.

spinner, the reverse of the trend in *S. attenuata*. The skulls of the eastern and whitebelly spinners do not differ in proportion, but the whitebelly skull is on the average slightly larger. The skull of the Hawaiian spinner is longer and broader than those of the other three forms. The four series of specimens can easily be separated statistically (Perrin 1972a).

We know little about the external appearance of the Costa Rican spinner, other than it is very long and slim (a 216-cm male weighed only 57 kg) and has a color pattern very much like that of the eastern spinner. The obviously disparate color patterns of the eastern, whitebelly, and Hawaiian forms can be compared in terms of differential development of a dorsal dark field (Perrin 1972b). The dorsal field is darkest and most extensive in the eastern form and lightest and least extensive in the Hawaiian form. In the Hawaiian form, an underlying dark cape shows strongly through the light dorsal field. The result is to make the coloration of the eastern, whitebelly and Hawaiian spinners effectively uniform, bipartite, and tripartite, respectively. In some apparent intergrades from the area of overlap of the eastern and whitebelly ranges, the dark cape shows faintly through the dorsal field, but the ventral margin of the field is lower and more irregular than in the typical whitebelly spinner.

The dorsal fin of the adult male differs among the three races. In the eastern spinner the tip is forward of midlength of the fin base, giving the fin a reversed appearance. The forward cant is much more developed in some males than in others (Perrin 1972a). In the whitebelly form, the adult male fin is never "reversed" but usually triangular. In the Hawaiian form, it is always at least slightly falcate. Development of a ventral, postanal keel, of unknown function, is correlated with degree of forward cant of the dorsal fin. It is largest in eastern males and nearly absent in Hawaiian males.

The whitebelly form is on the average about 5 cm longer than the eastern form (Fig. 6) and is more robust, having a greater average girth at the axilla (Perrin 1972a). Few measurements are available for the Hawaiian spinner, but it ap-

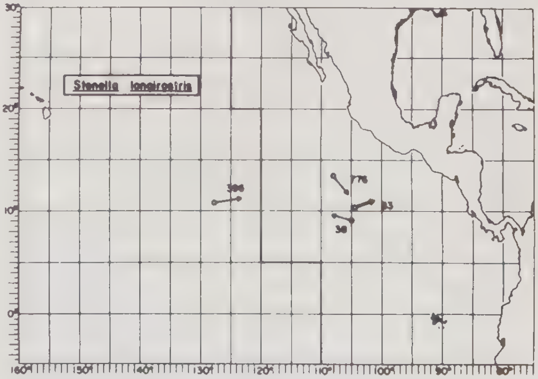

FIG. 8. Net movements of recovered tagged spinner dolphins, *S. longirostris*, with days at liberty.

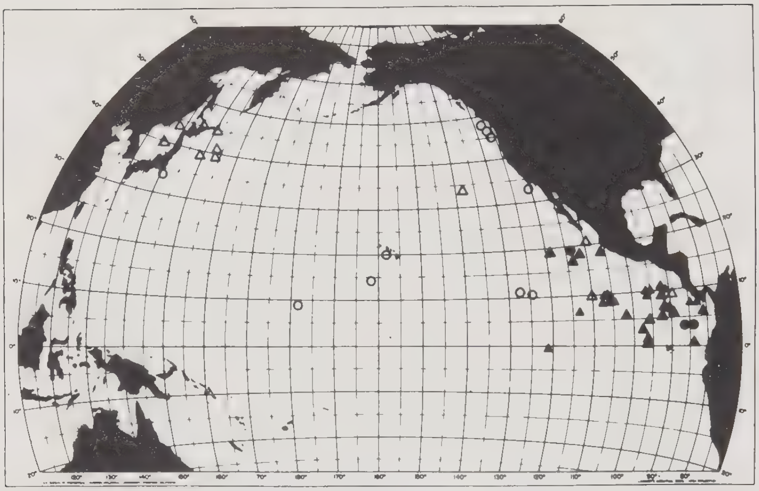

FIG. 9. *Stenella coeruleoalba* in the Pacific. Circles are specimen localities; triangles are sighting localities. Shaded symbols are new records. Open symbols are previously published records (Hubbs et al. 1973).

parently is, on the average, longer than the whitebelly spinner.

We have tagged 242 spinner dolphins (Fig. 7) and recovered five (Fig. 8). Time at liberty ranged from 38 to 776 days, and net distance traveled from 333 to 733 km. Two animals tagged together were recaptured together 83 days later. The limited results show less net movement than for *S. attenuata* and agree with the hypothesis of offshore (eastern) and far offshore (whitebelly) populations.

The four races of spinners deserve subspecific status, but, as is the case for the spotted dolphins, assignment of trinomials must wait until the question of how many species of spinner dolphin exist in the world's oceans has been settled. For the time being, they are best considered as unnamed subspecies of *S. longirostris* Gray.[2]

Stenella coeruleoalba — The striped dolphin was not known from the eastern tropical Pacific until 1970 (Hubbs et al. 1973). In addition to the published locality records (Hubbs et al. 1973) we now have 36 more records, including three for which specimens were collected (Fig. 9). The known range has been extended south to below the equator and east to the Panama Bight. There may be a break in the distribution between about 10° and 17° N lat. This would make the distribution similar to that of *Delphinus* in the eastern tropical Pacific (W. E. Evans personal communication) and may indicate that there is more than one stock. Enough specimens have now been collected from the tropical Pacific (26) so that morphological comparisons can begin to be made between this population or populations and those in the western Pacific and Japan.

Discussion

Geographical races exist for each species of small delphinid that has been closely looked at in the eastern tropical Pacific. It seems reasonable to assume that the eastern Pacific (and world) populations of the other, less well-known delphinids, e.g. *S. coeruleoalba*, *Tursiops*, and *Globicephala*, are similarly subdivided. This points out the need for emphasis on research and management at the stock level.

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[2] *Note*: There is room for speculation about the identity of Gray's holotype (Perrin 1972a). The spinner skull that Schlegel in 1846 figured and redescribed as the holotype may not have been the specimen examined by Gray. Gray described his specimen as having a strongly carinated palate, a feature present in *Delphinus* but not in *Stenella*. If Schlegel was indeed mistaken about the origin of the specimen he examined, *longirostris* may be preoccupied by *Delphinus* and unavailable for *Stenella*. However, in the interest of stability of nomenclature and in the light of other known inconsistencies in Gray's work, it seems best to ignore this uncertainty now and retain the long-used *longirostris* for the spinners.

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VARIATION OF SPOTTED AND SPINNER PORPOISE (GENUS STENELLA) IN THE EASTERN TROPICAL PACIFIC AND HAWAII

BY

WILLIAM F. PERRIN

ABSTRACT

Spotted and spinner porpoise occur in coastal and offshore tropical waters of the eastern and central Pacific, as well as elsewhere in world tropical waters. They are important in the tropical yellowfin tuna fishery as indicators and aggregators of tuna. In the eastern Pacific, the range of both is a triangle with the base the coastline from Cabo San Lucas, Mexico to Columbia, and the apex extending seaward to about 10°N latitude, 145°W longitude.

Variation owing to ontogeny, sexual dimorphism, individual variation, and geographical differentiation in coloration, external size and shape, and skeleton are described in qualitative and quantitative terms, and three geographical races of the spotted porpoise, *Stenella attenuata* (Gray, 1846), and four of the spinner porpoise, *S. longirostris* (Schlegel,1841), (nomenclature is provisional) are defined.

SPOTTED PORPOISE

Spotted porpoise are unspotted at birth. During adolescence, dark spots appear on the ventrum, followed by appearance of light spots on the dorsum. The ventral spots enlarge and merge, giving the adult a uniform gray appearance below. There is no sexual dimorphism in the color pattern. Individual variation is greatest in the intensity of dorsal spotting. The dorsal spotting also varies geographically. Animals from the far eastern Pacific are on the average most heavily spotted. The Hawaiian form is nearly unspotted as an adult.

The analysis of ontogeny of external dimensions and shape of the spotted porpoise was based on 214 specimens. Changes in proportions during postnatal development are owing primarily to a disproportionate rate of growth of the section of torso between the umbilicus and anus, combined with an early surge in growth of the snout. The head, dorsal fin, and flippers stop growing at puberty, but total body length and size of the flukes continue to increase into maturity. Adult females are on the average about 10 cm smaller than males, but have relatively longer snouts, greater girth, and greater fluke span. Individual variation is greatest in length of the snout. Of the appendages, the dorsal fin is most variable. Geographical variation is pronounced. Specimens from very near the coast are larger than offshore specimens in all torso dimensions and in fluke span. The offshore animals have longer flippers. The Hawaiian form has a larger head than the offshore form.

The skull of the spotted porpoise was analyzed in terms of groups of functionally related measurements. The functional systems have different patterns of postnatal development. The hearing apparatus is most precocious, followed by the vision apparatus, the braincase, the breathing and sound-producing apparatus, and the feeding apparatus, in that order. Skulls with 5 or more layers in the postnatal dentine can be considered "adult" for purposes of inclusion in taxonomic series. Only the anteriormost elements of the postcranial skeleton develop as rapidly as the skull. The remainder of the skeleton shows protracted growth (until at least 8-10 layers are present in the teeth). In general, males have larger braincases and shorter, broader rostra than females. Individual variation in the skull is greatest in the feeding apparatus. Geographical variation was examined in 147 skeletal specimens. Animals from less than 25 km from the coast in the eastern Pacific (n = 19), including the holotype of *S. graffmani* Lönnberg,1934), have larger skulls and proportionately more robust feeding apparatuses than do specimens from the offshore tuna fishery. Separation in many measurements is complete, but some overlap is to be expected when more specimens of the coastal form become available. Hawaiian specimens have larger skulls than do the offshore animals of the eastern Pacific, but disparity in the proportions of the feeding apparatus is not as great as between the coastal and offshore forms. The differences among the three forms in skull proportions cannot be ascribed to simple heterogenic growth. Selection apparently impinges on a component of the variance of the feeding apparatus which is to some degree independent of a general size factor.

[1] Southwest Fisheries Center, La Jolla, Calif.

The coastal, offshore, and Hawaiian forms of spotted porpoise belong to a single species. The name *S. attenuata* (Gray, 1846) – from unknown locality – is provisionally applied, following True's (1906) work on the Hawaiian form. Because of the unsettled state of the taxonomy (especially the nomenclature) of the genus, a trinomial can be applied only to one of the geographical races, namely the coastal form: *S. attenuata graffmani* (Lönnberg, 1934). The offshore and Hawaiian forms are referred to provisionally as *S. attenuata* subsp. A and B, respectively.

SPINNER PORPOISE

Body attenuation in the spinner is less during postpubertal development than in the spotted porpoise. Adults have proportionately larger appendages than do adults of the spotted porpoise. The dorsal fin is canted forward to varying degree in large males. Males and females do not differ in proportionate girth or size of appendages. The eastern Pacific specimens fall into three geographical series based on external size, shape, and coloration. "Costa Rican" spinners (coast of Central America) are longest and most attenuate. "Eastern" spinners (North American coast to about 800 km offshore) are intermediate, and "whitebelly" spinners (>800 km offshore) are greatest in girth and have the least canted dorsal fins. The Hawaiian spinner has a color pattern most like that of the whitebelly form but is larger.

The skeleton of the spinner porpoise develops in the same pattern as in the spotted porpoise, except that cranial development proceeds more rapidly. The adult configuration is reached when 4 layers have been laid down in the dentine, and postpubertal elongation of the axial skeleton is less protracted, rendering overall growth more isogonic. Sexual dimorphism is negligible. Patterns of individual variation are similar to those in the spotted porpoise. Among the geographical forms, the Costa Rican spinner is most divergent, having a very long, attenuate rostrum. Differences between the eastern and whitebelly series are comparatively slight. The Hawaiian spinner has a longer, broader skull than the eastern Pacific forms.

Taxonomy of the spinner porpoise is as confused as that of the spotted porpoise, but again there appears to be but a single species in the Pacific. The name *Stenella longirostris* (Schlegel 1841) is applied provisionally. The Costa Rican, eastern, whitebelly, and Hawaiian spinners deserve subspecific status within *S. longirostris*, but trinomials cannot be assigned until the taxonomy has been adequately reviewed on a worldwide basis. Skulls of unknown provenance can be classified with discriminant functions.

INTRODUCTION

The major objective of this study is to describe the variation among the porpoise of the genus *Stenella* in the eastern tropical Pacific. It is hoped this will contribute to a revision of the genus. For a variety of reasons, such a revision has been difficult to achieve in the past. The taxonomy of the genus is notoriously confused and difficult. As True (1889) stated,

> The genus [*Prodelphinus*, = *Stenella*] comprises a large number of nominal species, for the most part founded upon single skulls. Nearly every large collection contains a considerable number of skulls which may be assigned to this genus. It is found, however, in many cases that when a large number of these skulls is brought together they tend to form continuous series. The differences between the extremes of these series are often striking and perfectly definable, but in the middle they melt away and elude definition. From this fact and from the absence of material the task of revising the species of this genus is a very difficult and disheartening one.

An additional difficulty is that data on external appearance very seldom accompany skeletal specimens in collections, and further, whole specimens are often identified in the field on the basis of external characteristics alone. As Fraser (1966) noted, the situation encountered by the early cetologists still exists.

A primary goal of this study, therefore, was to obtain large series of the spotted and spinner porpoise of the genus *Stenella* occurring in the eastern tropical Pacific, and to describe their variation in coloration, external morphology, and osteology of the cranium and postcranial skeleton owing to development, sexual dimorphism, individual differences within schools, and geographical differentiation.

A complete revision of the genus will require examination of more material than was available to me (for example, the type specimens, most of which are in European collections, have not been examined). I found, however, basis for some comments on the taxonomy of the eastern Pacific forms. I also examined photographs and skeletal material of representatives of the genus from Hawaiian waters and make some comments about the taxonomic positions of those forms.

METHODS

EXTERNAL MEASUREMENTS

To meet logistical constraints imposed by sampling conditions aboard commercial fishing vessels, I reduced the list of standard external measurements for cetaceans compiled by the Committee on Marine Mammals of the American Society of Mammalogists (1961, K.S. Norris ed.) by about half, by (1) deleting those measurements that would be difficult to make accurately, such as maximum girth and length of the anal slit, and (2) deleting further measurements on the basis of intercorrelation, since highly correlated variables produce redundant information. Principal components analysis is a method of summarizing a large number of intercorrelated data in terms of a smaller number of independent axes. I applied principal components analysis to 20 measures of 10 animals in an attempt to evaluate the 20 variates in terms of their relative contributions to the "principal components" of the variance. I used a computer program BMDOIM prepared by the Health Sciences Computing Facility of the University of California Biomedical Center at Los Angeles (Dixon, 1965).

After the deletions, I was left with a list of 14 measurements to be made at sea, which I was confident were the best choices to be made from the original list of 34. All the measurements, including those made only ashore (see below) are listed in table 1 and shown in figure 1. Measurements were made point-to-point on the left side, with a large pair of calipers. The measurement methods proposed by the Committee on Marine Mammals of the American Society of Mammalogists (1961) for several applicable dimensions specify axial projections rather than point-to-point measurements. I feel that the point-to-point method is more precise, is readily applicable for smaller cetaceans, and yields values that are convertible into axial projections, provided that good photographs in several aspects have been made. Girths were measured with a cloth tape. In measuring flipper width, the flipper was pulled out from the body to a position at which the skin was neither depressed nor elevated at the anterior or the posterior insertion, and greatest width parallel to the body axis was then measured.

For specimens examined at sea, the suite of measurements includes the 14 selected as explained above. Measurements taken ashore include 8 additional measurements from those deleted to yield the at-sea list, but do not include measurements of the dorsal fin, flippers, and flukes because of obvious dehydration of these features owing to freezing.

Sample sizes also vary because of occasional mutilated animals.

To allow comparison of my point-to-point measurements with those taken by other workers, in some instances it was necessary to convert them to parallel-to-major-axis equivalents, using conversion coefficients derived from measurements of photographs of typical specimens.

MULTIVARIATE ANALYSIS OF SKELETON MEASUREMENTS

Discriminant analysis was used to study subspecific differences in the skull. This method uses linear compounds of a set of multiple measurements to discriminate between groups. First used by Fisher (1936), the method provides the best linear functions for discrimination, as proved by Rao (1952). The method was first used in analysis of morphology of cetaceans by Ichihara (1957) in his study of fin whales (*Balaenoptera physalus* L.) in the North Pacific and has been employed extensively in the systematics of other vertebrate groups (Jolicoeur, 1959; Jameson, Mackey, and Richmond, 1966).

Multiple discriminant functions are computed as the vectors associated with the latent roots of the determinantal equation

$$|W^{-1}B - \lambda I| = 0$$

where W = pooled within-group variance-covariance matrix, and B = total variance-covariance matrix T − W.

Table 1. External measurements of porpoise

1. Length, total (tip of upper jaw to deepest part of notch between flukes).
2. Length, tip of upper jaw to center of eye.
3. Length, tip of upper jaw to apex of melon (snout length).
4. Length of gape (tip of upper jaw to angle of gape).
5. Length, tip of upper jaw to external auditory meatus.
6. Center of eye to external auditory meatus (direct).
7. Center of eye to angle of gape (direct).
8. Center of eye to center of blowhole (direct).
9. Length, tip of upper jaw to blowhole along midline.
10. Length, tip of upper jaw to anterior insertion of flipper.
11. Length, tip of upper jaw to tip of dorsal fin.
12. Length, tip of upper jaw to midpoint of umbilicus.
13. Length, tip of upper jaw to midpoint of genital aperture.
14. Length, tip of upper jaw to center of anus.
15. Girth, on a transverse plane intersecting axilla.
16. Girth, on a traverse plane intersecting the anus.
17. Length, flipper (anterior insertion to tip).
18. Length, flipper (axilla to tip).
19. Width, flipper (maximum).
20. Height, dorsal fin (fin tip to base).
21. Width, flukes (tip to tip). [referred to below as "span of flukes"]
22. Distance from nearest point on anterior border of flukes to noth [referred to below as "width of fluke"]

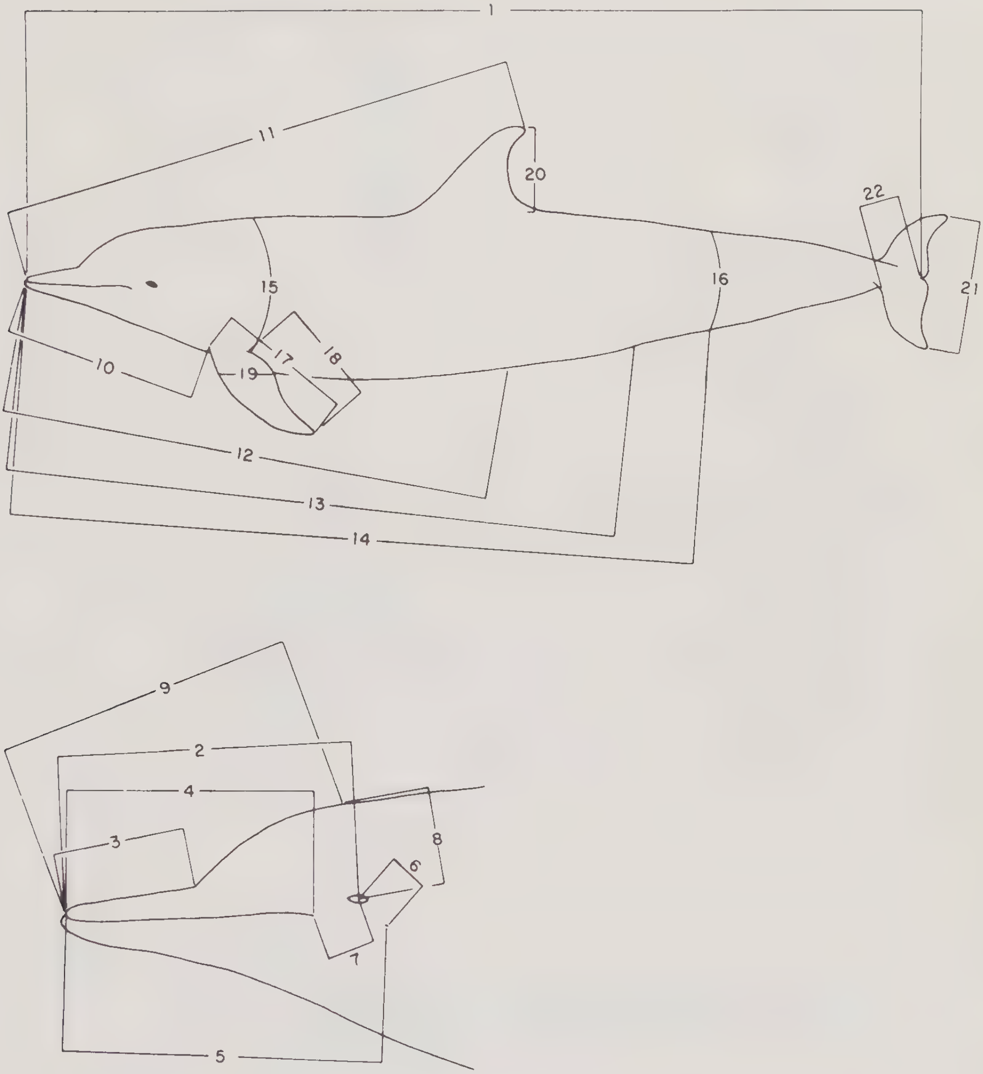

Figure 1. Point-to-point external measurements. Numbers refer to table 1.

The approach effectively accomplishes separation of "between" variance from "within" variance, standardizes it by "within variance," and then throws orthogonal axes through it in such a way that as much of it as possible is accounted for by the first axis, as much as possible of the remainder by the second axis, and so on. Excellent expositions of discriminant analysis have been presented by Cooley and Lohnes (1962) and Seal (1964). UCLA Biomedical Computing Program BMD07M, Stepwise discriminant analysis (Dixon, 1965) was used in this study.

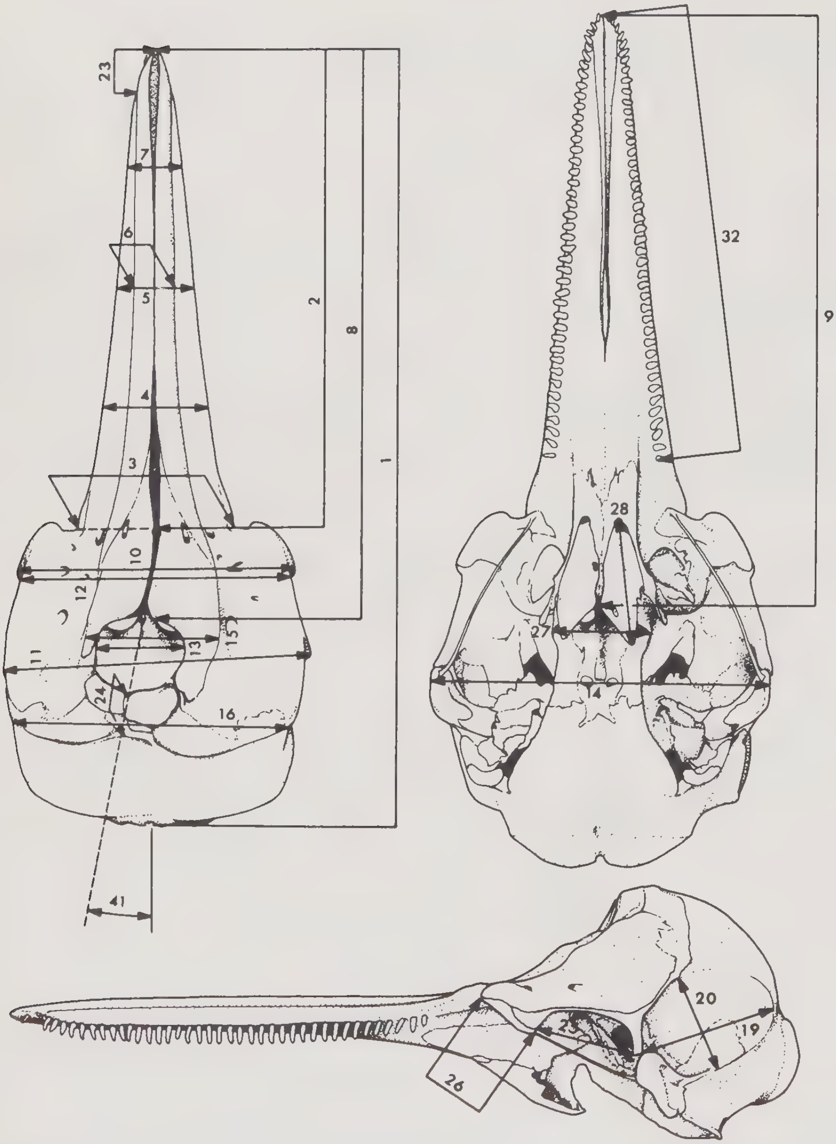
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Figure 2. Measurements of the cranium. Numbers refer to table 2 (continued).

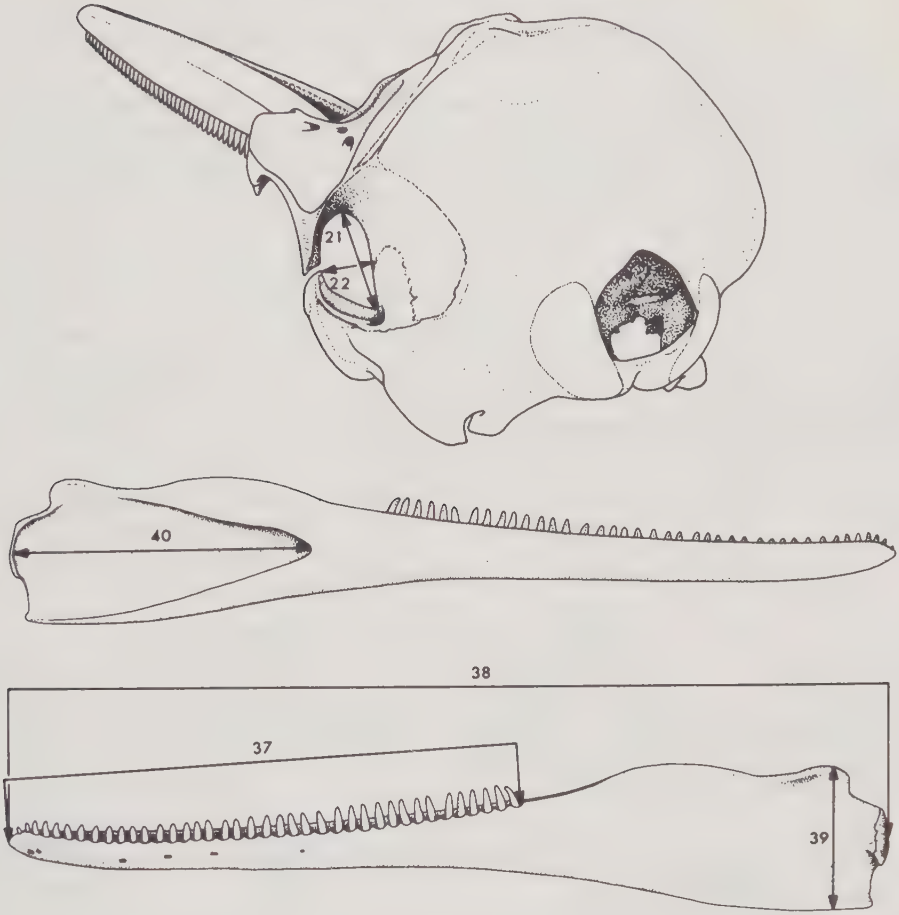


Figure 2 (continued). Measurements of the temporal fossa and mandible. Numbers refer to table 2 (continued).

SKELETON MEASUREMENTS AND MERISTICS

One hundred and nineteen (119) measurements and meristic observations were employed (table 2, fig. 2). The cranial measurements comprise those used by Fraser (1950 and 1966) plus several devised by me. The list of postcranial measurements and meristics is an amalgam of those used previously by Fraser and other workers in the taxonomy of *Stenella*, including Lütken (1889), Flower (1884), True (1889), and others. To facilitate automatic data processing, each was assigned a number and treated independently in lists and tables.

All linear measurements were taken with calipers and read to the nearest millimeter. Internal length of the braincase was measured with the interior extension of a set of dial calipers. Angle of asymmetry was measured with a flexible protractor. Additional observations were made on the state of fusion of the epiphyses of the manus and of the hyoid bones, on the degree of closure of cranial sutures, and on various qualitative aspects of the skeleton.

EXAMINATION OF LAYERS IN TEETH

To inspect layering, teeth were cut longitudinally with a diamond saw into sections 12/1000-inch (0.31 mm) thick. The sections were cleared in glyercine and alcohol, mounted under cover slips in balsam, and examined with transmitted light under a compound microscope. Postnatal dentinal layers were counted to the nearest half layer. The layering has not yet been securely calibrated but is certainly correlated with age. Neonatal animals have only the neonatal tooth with no evidence of layering in the dentine. Accumulation of layers is correlated with external and skeletal growth and the progress of skeletal fusion (described below) and with accumulation of corpora of ovulation in females (unpublished data). The layers are often difficult to read, and the values used here are the averages of several counts for each specimen. The several readings for each tooth were separated by days or weeks and teeth read each time without referring to the specimen numbers or the values obtained previously. Average accuracy is estimated at ± 1 layer for teeth with less than 5 layers, and ± 2 layers for teeth with more than 5 layers.

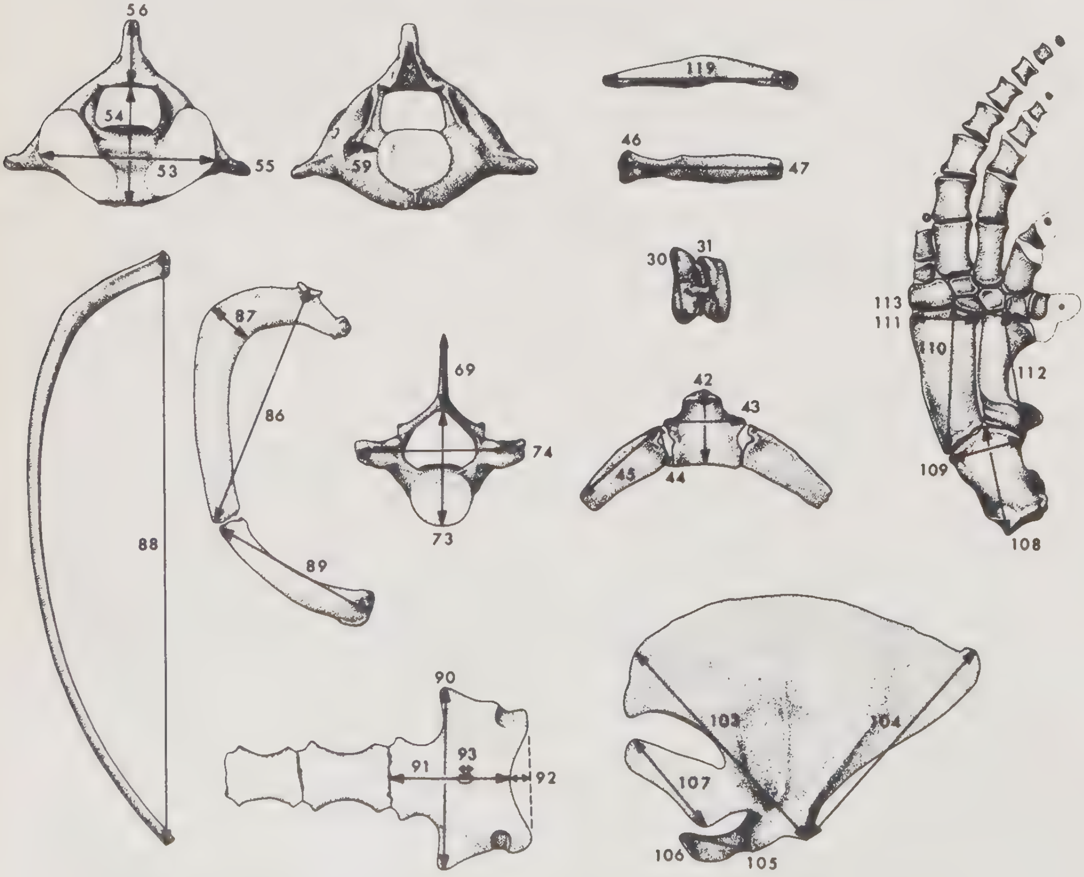


Figure 2 (continued). Postcranial skeletal measurements. Numbers refer to table 2.

Table 2. Skeletal measurements and meristics (continued)

1. Condylobasal length – from tip of rostrum to hindmost margin of occipital condyles.
2. Length of rostrum – from tip to line across hindmost limits of antorbital notches.
3. Width of rostrum at base – along line across hindmost limits of antorbital notches.
4. Width of rostrum at 60 mm anterior to line across hindmost limits of antorbital notches.
5. Width of rostrum at midlength.
6. Width of premaxillaries at midlength of rostrum.
7. Width of rostrum at 3/4 length, measured from posterior end.
8. Distance from tip of rostrum to external nares (to mesial end of anterior transverse margin of right naris).
9. Distance from tip of rostrum to internal nares (to mesial end of posterior margin of right pterygoid).
10. Greatest preorbital width.
11. Greatest postorbital width.
12. Least supraorbital width.
13. Greatest width of external nares.
14. Greatest width across zygomatic processes of squamosal.
15. Greatest width of premaxillaries.
16. Greatest parietal width, within postemporal fossae.
17. Vertical external height of braincase from midline of basisphenoid to summit of supraoccipital, but not including supraoccipital crest (not illustrated).
18. Internal length of braincase from hindmost limit of occipital condyles to foremost limit of cranial cavity along midline (not illustrated).
19. Greatest length of left posttemporal fossa, measured to external margin of raised suture.
20. Greatest width of left posttemporal fossa at right angles to greatest length.
21. Major diameter of left temporal fossa proper.
22. Minor diameter of left temporal fossa proper.
23. Projection of premaxillaries beyond maxillaries measured from tip of rostrum to line across foremost tips of maxillaries visible in dorsal view.
24. Distance from foremost end of junction between nasals to hindmost point of margin of supraoccipital crest.
25. Length of left orbit-from apex of preorbital process of frontal to apex of postorbital process.
26. Length of antorbital process of left lacrimal.
27. Greatest width of internal nares.
28. Greatest length of left pterygoid.
29. Greatest width of anterior overhang of supraoccipital crest (not illustrated).
30. Greatest length of bulla of left tympanoperiotic.
31. Greatest length of periotic of left tympanoperiotic.
32. Length of upper left tooth row – from hindmost margin of hindmost alveolus to tip of rostrum.
33. Number of teeth – upper left.
34. Number of teeth – upper right.

Table 2 (continued). List of skeletal measurements and meristics (continued)

35. Number of teeth – lower left.
36. Number of teeth – lower right.
37. Length of lower left tooth row – from hindmost margin of hindmost alveolus to tip of mandible.
38. Greatest length of left ramus.
39. Greatest height of left ramus at right angles to greatest length.
40. Length of left mandibular fossa, measured to mesial rim of internal surface of condyle.
41. Deviation of skull from symmetry in dorsal view, in degrees.
42. Length of basihyal along midline.
43. Greatest width of basihyal.
44. Greatest width of left thyrohyal proximally.
45. Greatest length of left thyrohyal.
46. Greatest width of left stylohyal.
47. Greatest length of left stylohyal.
48. Number of thoracic vertebrae, defined as equal to number of ribs on side with greatest number.
49. Number of lumbar vertebrae.
50. Number of caudal vertebrae. The very small segment at the tip of the column was counted as a vertebra. If this segment was missing, the column was considered to be damaged, and the count was not made.
51. Total number of vertebrae.
52. Number of fused cervical vertebrae.
53. Greatest width of articulating surface of atlas.
54. Height of atlas – from internal anterodorsal margin of neural canal to bottom of anterior face of body.
55. Length of lateral process of atlas – from margin of anterior articulating surface to farthest point at end of process.
56. Greatest length of neural spine of atlas.
57. Height of dorsal ridge of atlas in anterior view (not illustrated).
58. Length of right dorsolateral spine of atlas (not illustrated).
59. Length of left lateral process of axis – from margin of posterior articulating surface to distal end of process.
60. Number of cervical vertebrae with incomplete neural arches.
61. Cervical vertebra on which left ventrolateral process reaches greatest development.
62. Vertebra on which first vertical perforating foramen appears.
63. First vertebra with greatly reduced metapophyses.
64. Last vertebra with distinct transverse processes.
65. Last vertebra with distinct neural process.
66. First vertebra with unfused epiphysis.
67. Last vertebra with unfused epiphysis.
68. First caudal vertebra with vertical neural spine.
69. Length of neural spine of first thoracic vertebra – from anterodorsal margin of neural canal to tip of spine.

Table 2 (continued). List of skeletal measurements and meristics (continued)

70. Length of neural spine of second thoracic vertebra.
71. Length of neural spine of tenth thoracic vertebra.
72. Length of neural spine of last thoracic vertebra.
73. Height of first thoracic vertebra – from internal anterodorsal margin of neural canal to bottom of anterior face of body.
74. Greatest width of first thoracic vertebra – across lateral processes.
75. Height of first lumbar vertebra (not illustrated).
76. Greatest width of first lumbar vertebra (not illustrated).
77. Length of 23d centrum, exclusive of epiphyses, along ventral midline (not illustrated).
78. Number of vertebral ribs – left.
79. Number of vertebral ribs – right.
80. Number of two-headed ribs – left.
81. Number of two-headed ribs – right.
82. Number of floating ribs – left.
83. Number of floating ribs – right.
84. Number of sternal ribs – left.
85. Number of sternal ribs – right.
86. Greatest length of first left vertebral rib.
87. Width of first left vertebral rib at apex of proximal curvature.
88. Greatest length of longest left vertebral rib.
89. Greatest length of first left sternal rib.
90. Greatest width of manubrium.
91. Length of manubrium along midline.
92. Depth of anterior notch of manubrium.
93. Length of foramen in manubrium.
94. Number of mesosternal elements.
95. Number of mesosternal elements fused.
96. Number of chevron bones.
97. Number in foremost series of fused chevron bones.
98. Vertebra bearing first chevron bone.
99. Vertebra bearing last chevron bone.
100. Greatest length of left half of first chevron bone (not illustrated).
101. Greatest length of left half of largest chevron bone (not illustrated).
102. Greatest length of left half of last chevron bone (not illustrated).
103. Height of scapula – from posterior margin of glenoid fossa to coracovertebral angle.
104. Length of scapula – from posterior margin of glenoid fossa to glenovertebral angle.
105. Greatest length of coracoid process – from anterior margin of glenoid fossa.
106. Greatest width of coracoid process.
107. Greatest width of metacromion process – from apex of ventral curvature to vertebral apex.
108. Greatest length of humerus, measured on ventral side of flipper.
109. Greatest width of humerus distally.
110. Greatest length of radius.
111. Greatest width of radius distally.
112. Greatest length of ulna

Table 2 (continued). List of skeletal measurements and meristics

113. Transverse breadth of proximal row of carpals.
114. Number of ossified phalanges in first digit.
115. Number of ossified phalanges in second digit.
116. Number of ossified phalanges in third digit.
117. Number of ossified phalanges in fourth digit.
118. Number of ossified phalanges in fifth digit.
119. Greatest length of left pelvic rudiment.

The spotted porpoise is of great economic importance in the eastern tropical Pacific. A spotted porpoise is the form most sought after by American fishermen in their quest for tuna associated with porpoise schools (Alverson, 1963; Perrin, 1968, 1969, 1970*b*; Perrin and Hunter, 1972).

American fishing vessels range the entire eastern Pacific in their search for tuna. Logbooks maintained by the tuna captains show that thousands of net sets made in the Commission Yellowfin [tuna] Regulatory Area (CYRA) in the period 1963-1970 were noted as made on fish associated with schools of spotted porpoise (fig. 3, unpublished data, Inter-American Tropical Tuna Commission). Logbook data are not available for the portion of the eastern Pacific outside the CYRA. Figure 4 shows all confirmed locality records for spotted porpoise in the eastern Pacific, including the area outside the CYRA. This includes published records, localities of museum specimens, localities of material collected during government studies, and sighting records collected by government scientists aboard research vessels and tuna seiners. The distribution appears to be bounded on the north by the southwestward extension of the cold California Current and on the south by the northwestward extension of the cold Peru Current (South Equatorial Current). There is an apparent gap between the westernmost limits of the recorded range (at about 145°W) and Hawaiian waters, where a spotted porpoise occurs (referred to *S. attenuata* [Gray, 1846] by True [1906] and subsequent authors). Despite extensive exploratory fishing by commercial tuna vessels and considerable activity in and through the area by government research vessels based on the West Coast and in Hawaii, there have been no recorded sightings of spotted porpoise in this region. The break in distribution, if real, is approximately 700 miles wide. Spotted porpoise also occur to the south of Hawaii in the Phoenix Islands (Peale, 1848) and in the Marquesas (personal communication from K. S. Norris), but the extent of continuity, if any, of these populations is unknown.

HISTORICAL REVIEW

Atlantic Ocean

Linnaeus (1758) described the genus *Delphinus* ("*Dentes in maxilla utraque. Fistula in capite*") and the species *D. delphis ("D. corpore oblongo subtereti, rostro attenuato acuto*") from "Oceano Europaeo," based on illustrations by earlier workers. The first indication that more than one species of long-snouted toothed cetacean exists in the Atlantic came when A. J. Pernetty (1769), in an account of a voyage to the Falkland Islands, described a spotted porpoise captured 27 days after his vessel had passed Boa Vista in the Verde Cape Islands [16°44′S, 35°10′W fide Fraser, 1950], as follows (from the 1773 translation):

> On the 20th of November [1763] at eight in the morning we took a porpoise of about a hundred weight. I painted him from the life, but without preserving any proportion to his bulk. For the figure of him see the plate annexed . . . . The porpoise, which I am describing here (and all those we took were of the same kind) is, as I apprehend, of that species, which are called *moines der mer* [monks of the sea]. The fore part of the head terminates in a roll

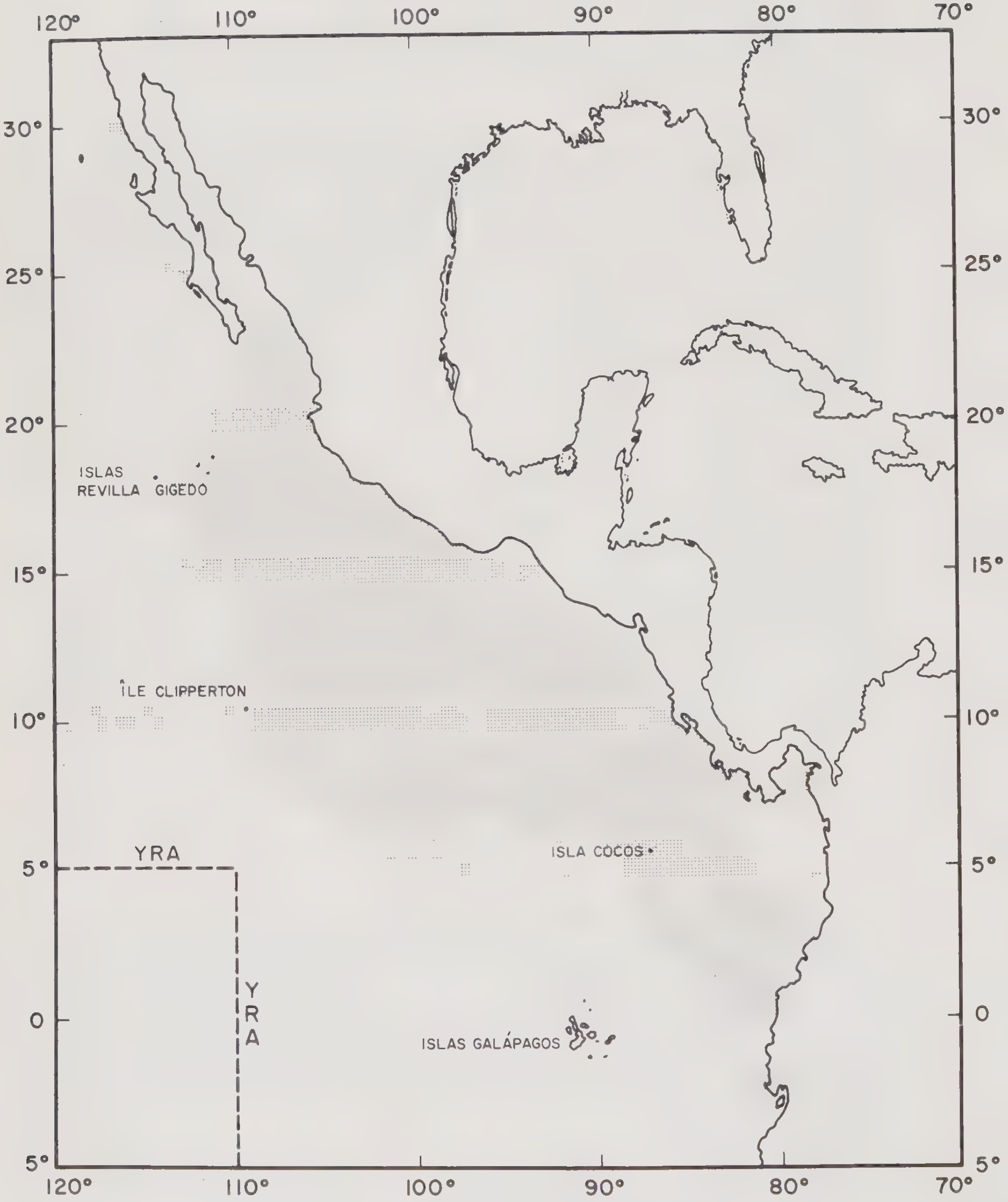

120°
110°
100°
90°
80°
70°
30°
25°
20°
15°
10°
5°
0
5°
ISLAS REVILLA GIGEDO
ÎLE CLIPPERTON
YRA
YRA
ISLA COCOS
ISLAS GALÁPAGOS

Figure 3. Distribution of purse-seine sets on spotted porpoise in the Commission Yellowfin (tuna) Regulatory Area, 1963-1970, by 1/2-degree squares. From tuna boat logbook data provided by the Inter-American Tropical Tuna Commission.

> near the beginning of the snout or beak, answering to the border of the cowl. The black is blackish, and the belly of a grey, consisting of a pearl colour, somewhat inclining to yellow, interspersed with black and iron-grey spots.

Pernetty's figure shows a spotted porpoise much resembling a large subadult of the offshore spotted porpoise of the eastern Pacific in shape of dorsal fin and in size, density, and distribution of spots, with a band of pigment extending from flipper to gape (see Perrin, 1970*a*). Bonnaterre (1789) considered the spotted animal to be merely a variety of *D. delphis.* Blainville (in Desmarest, 1817) described *Delphinus Pernettensis* on the basis of Pernetty's description and figure. Desmarest later (1820-1822) emended the name to *D. Pernettyi.*

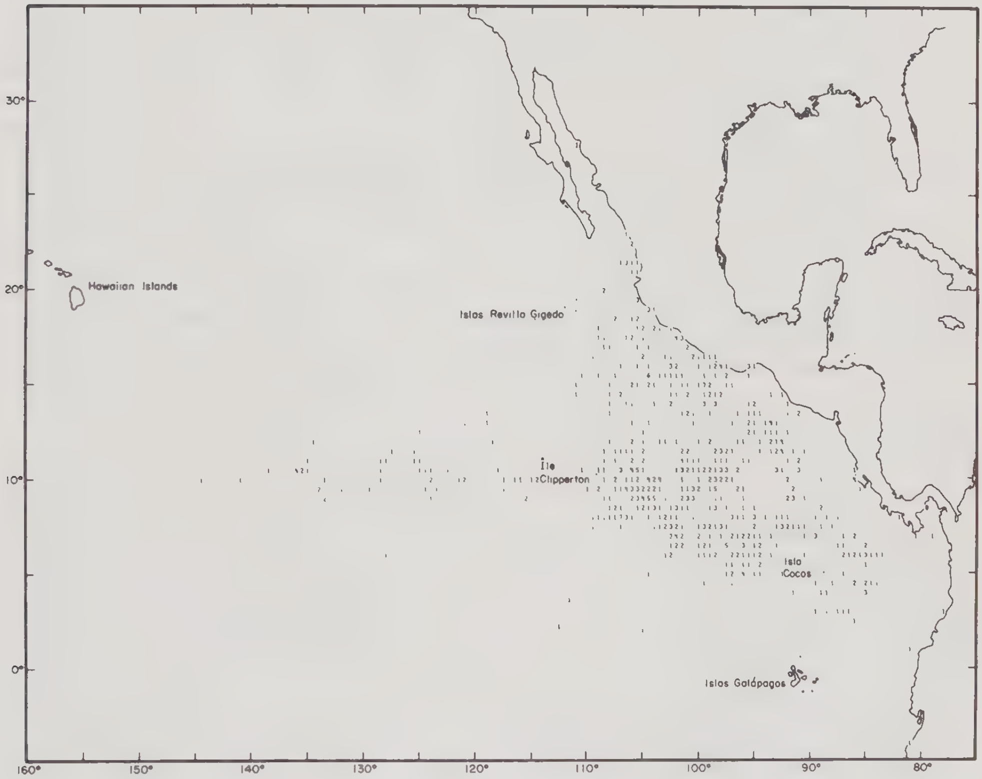

30°
20°
10°
0°
Hawaiian Islands
Islas Revillo Gigedo
Ile Clipperton
Isla Cocos
Islas Galápagos
160°
150°
140°
130°
120°
110°
100°
90°
80°

Figure 4. Distribution of locality records of spotted porpoise in the eastern tropical Pacific, from museum specimens, sightings from research vessels, and sightings by scientific observers aboard commercial fishing vessels. Numbers represent records per 1/2-degree square.

Pernetty probably observed two species of porpoise on his voyage. Six days out of the Cape Verde Islands, he observed a school of "some hundred porpoises" that "leaped at least three or four feet high, and turned round not less than three times in the air, as if they had been on a spit." Such gyrations on a longitudinal axis are typical of the spinner porpoises and not of the spotted porpoises. Thus, it appears that despite Pernetty's thinking the contrary, the animal he painted was almost certainly not of the same species as those seen 21 days before and a thousand miles to the north. All authors who have since discussed Pernetty's animal, including Hershkovitz (1966), have assumed that a single species was involved and that Pernetty saw spotted animals at the first position mentioned in his account (near Cape Verde) as well as at the second (some 750 miles off Brazil at 16°S). Van Bree (1970a), however, has determined that Pernetty in the second edition of his work (1770) stated that the specimen was taken between the islands Boa Vista and Maio of the Cape Verde Islands and that only a seabird was taken off Brazil. Van Bree also moved that the specific names *pernettensis* de Blainville 1817 and *pernettyi* Desmarest 1820 be suppressed by the International Commission in Zoological Nomenclature, as *nomina oblita.*

Following Pernetty's account, the next published mention of a long-snouted porpoise distinct from *D. delphis* was by G. Cuvier (1812) who, in a report on cetaceans taken on the coast of France, stated (p.9): *"Or, le Muséum possède plusiers têtes de deux vrais dauphins à museau grêle, differentes de celles du delphis et du tursio.*

Les uns ont les mêmes dents grêles et pointues que le delphis, mais seulement au nombre de 35 partout, en totalité 140. Leur museau est déprimé comme celui du delphis, mais un peu plus court à proportion. Nous n'avons acune notion de l'animal entier.

And on p. 14:4°. *Le dauphin vulgaire à 180 dents, D. delphis, et 5°. cet autre dauphin dont nous avons parlé ci-dessus à 140 dents ou environ, que nous appellerons provisoirement D. dubius."*

These two brief paragraphs constitute the description of *D. dubius.* G. Cuvier neither figured the species nor designated type specimens. Such was not the usual practice in his time. The identity of the skulls examined by him remains in question. The type locality also remains unknown, since Cuvier stated only that the skulls were in possession of the Paris Museum, implying but not stating explicitly (seemingly because of ignorance of their origin) that they had come from the coast of France. In the 1817 edition of his *Le Règne Animal* G. Cuvier appended a footnote to the account of *Delphinus delphis L.*: *"J'ai plusiers têtes de dauphin qui ont constamment trente-sept dents partout, et qui appartiennent probablement à une espèce particulière."*

Desmarest (1817) treated *D. dubius,* apparently after having personally examined G. Cuvier's material and stated that the tooth count was 37 to 38 in each side of each jaw for a total of 148. It can be assumed that he examined the same skulls described by Cuvier, because Cuvier specified "140 dents ou environ" and later amended his tooth count to 37. He also noted that the skulls were in general smaller than those of *D. delphis,* with a finer, more pointed and conical rostrum not inflated in the middle.

In the second edition of *Ossemens Fossiles* (1823), G. Cuvier supplemented his description of *D. dubius* by stating that the rostrum is narrower and flatter underneath than that of *D. delphis* and that the vomer is slightly exposed longitudinally between the premaxillaries and maxillaries (the latter condition, however, sometimes is also present in *D. delphis).* He also included cranial measurements for *D. dubius.*

Lesson (1828) stated that *D. dubius* lives on the coasts of Europe, presumably on the basis of Cuvier's inclusion of the description in a report on cetaceans taken on the coast of France. In the 1829 edition of *Le Règne Animal*, G. Cuvier again asserted, without specification, that the form occurs in European waters. He also stated that it resembles *D. delphis* in coloration.

F. Cuvier in 1829 (in St. Hillaire) published a color plate and description of a specimen from Cape Verde that he referred to *D. dubius*, but it is not known whether G. Cuvier concurred in the decision. The animal shown ("*quatre pieds six pouces*" long) very much resembles a young subadult or large calf of the spotted porpoise of the eastern Pacific, yet unspotted, with a definite flipper stripe to the gape. F. Cuvier later (1836) said that this specimen was used by Dussumier as the basis for description of *D. frontalis* (description written by G. Cuvier, 1829) before he knew of the existence of *D. dubius*, and that the skull corresponded with *D. dubius* in tooth count (36 vs. 35-38). With this statement, F. Cuvier in effect placed *D. frontalis* (known to be from Cape Verde) in the synomymy of *D. dubius* (unknown locality). His brother apparently did not agree with this, because when he presented Dussumier's description (G. Cuvier, 1829), he stated that *D. frontalis* is similar to *D. dubius* but differs in tooth count and coloration.

Pucheran (1856*a*) published external measurements of the type specimen of *D. frontalis*. The total length (144 cm) agrees well with the idea that the animal was a subadult. True (1889) measured a single skull in the Paris Museum (no. a3035), presumably the type of *D. frontalis*.

F. Cuvier (1829), in the same paper in which he described the specimen from Cape Verde which he referred to *D. dubius*, published a plate of another, similar animal from near the Cape Verde Islands, harpooned by Dussumier, which he called "*dauphin bridé No. 5*," describing the color pattern as follows,

> *Il est nôiratre sur le dos: cette couleur pâlit vers les flancs, et le ventre est blanc. Sa tete est noire en dessus; ces côtés ont une teinte cendrée, et une bande plus sombre forme sur les joues une moustache qui s'étend de l'angle de la gueule jusqu'au-delá des yeux.*

The plate, subsequently often reprinted, does not jibe very well with the description; later (1836) F. Cuvier stated that only the description was accurate. If, however, the lower margin of the dark field anteriorly can be taken to represent the "band on the chops," the pattern can be construed to match that of the spotted porpoise of the eastern Pacific, with a stripe from flipper to gape passing below the eye. This feature, according to F. Cuvier, prompted Dussumier to give the animal the name *Froenatus* ("*bridé*"). Length was "*4-1/2 pieds*," again that of an unspotted small subadult or large calf of the eastern Pacific spotted porpoise. The type specimen of *D. froenatus* (F. Cuvier) may be the second skull in the Paris Museum labeled *P. froenatus* (no. a3033) and measured by Gray (1850) and True (1889).

Gray (1866*b*) described still another species, *Clymene punctata*, from the Cape Verde Islands (16°40′N, 21°W), including a figure of the external appearance of the type specimen, with external and skull measurements. The animal was 6 feet long and spotted. The flipper band is not apparent in the figure, but the other elements of the color pattern are a close match to the spotted porpoise of the eastern Pacific (compare with fig. 5). The tooth counts $(\frac{40|40}{38|38})$ and skull measurements given by Gray also correspond closely. Unfortunately, the holotype was destroyed during World War II (fide Fraser, 1950).

Gray (1865) based *Steno capensis* on a skull from the South African Museum that presumably came from the Cape of Good Hope region and possibly from the South Atlantic. He stated that the skull was "somewhat like that of *Steno attenuatus* [described by Gray in 1846 from a skull from an unknown locality]." In the same paper he referred another skull from the South African museum to *Delphinus doris*, Gray (1846), described from an unknown locality.

Gervais in van Beneden and Gervais (1868-1880), erected the genus *Prodelphinus* to include all the species with *Delphinus delphis*-like skulls but with flat palates, including the forms with spots and 35 to 45 teeth under discussion here and subsumed by Flower (1884) in a section "D" of *Clymenia* Gray, 1868*a* (= *Clymene* Gray, 1864).

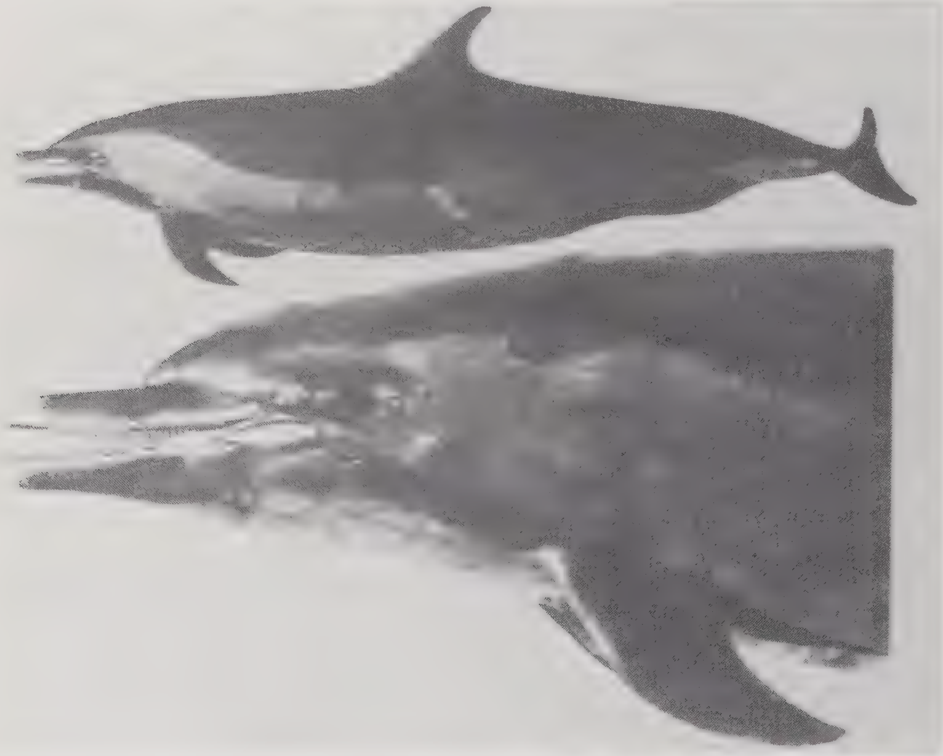


Figure 5. Two spotted porpoise from the far-offshore portion of the range of the spotted porpoise in the eastern Pacific: (top) field no. WFP 49 (USNM no. 396028), adult male, 197 cm, from 3°20′ N latitude, 110°44′ W longitude; (bottom) no. WFP 48 (USNM no. 396027), adult male, 190 cm, from 9°28′ N, 129°18′ W. Specimens photographed after having been frozen for several months and thawed in water. Note mottled appearance below and strong contrast between cape and lateral field.

True (1885) described a spotted porpoise from off Pensacola, Florida, in the Gulf of Mexico and referred it to *Prodelphinus doris* (Gray). He stated that the skull was "identical" with that of *D. palgiodon* Cope, 1866, described from an unknown locality, but that *D. plagiodon* should be a synonym of *P. doris.* True later (1889) reversed himself and separated *P. plagiodon* from *P. doris* on the basis of larger size of the skull and teeth and difference in color. In this paper he also described an individual captured off Hatteras, North Carolina. The plate of the 1884 specimen shows a very heavily spotted animal (216 cm long) with large dorsal fin and rather massive snout. A photograph of the same specimen was reproduced in the 1889 paper. In neither illustration is the position of the flipper stripe clearly discernible, although a slight increase in spot density suggests that it ran from flipper to eye.

Lütken (1889) reported on the skeletons of 16 animals, referred variously to *P. clymene* (Gray, 1850), *P. alope* (Gray, 1846), *P. doris*, and *P. attenuatus*, mostly from the tropical Atlantic. Of the six from known localities, the northernmost specimen (erroneously referred to *P. alope*, a spinner species) came from the mouth of the Bay of Biscay, lending credence to G. Cuvier's (1812) claim that *D. dubius* occurs on the coast of France. Another specimen was from outside the Azores and the remaining four were from between Africa and South America. He illustrated two varieties of "*Prodelphinus doris*." One is heavily spotted, and if a ground pattern is present it is obscure. The other is unspotted and corresponds in pattern, including presence of flipper band to gape, to a subadult or calf of the eastern Pacific spotted porpoise, to the species descriptions of *D. frontalis* and *D. froenatus* F. Cuvier (in St. Hillaire, 1829) and to the description of an animal from Cape Verde referred by F. Cuvier (in St. Hillaire, 1829) to *D. dubius* G. Cuvier.

I mention True's (1889) review of the *Delphinidae* here in the section on the Atlantic because his worldwide coverage of the spotted porpoise includes very complete review, summary, and synthesis of all the above and constitutes a landmark in the taxonomy of the group. He recognized three species from the Atlantic: *P. plagiodon* (Cope), *P. froenatus* (F. Cuvier), and *P. attenuatus* (Gray), "conjointly" considered with *P. malayanus* (Lesson 1828).

The next significant paper dealing with the taxonomy of the spotted porpoises in the Atlantic, that of Fraser (1950) appeared more than 60 years after True's work. Beddard's (1900) account and Fraser's earlier review (in Norman and Fraser, 1937) were based on True's findings. Oliver in 1922 revived *Stenella*, a subgenus of Gray (1866), as a generic designation to replace *Prodelphinus* Gervais.

Fraser reported on a spotted animal taken off the coast of Gabon (0°15′N, 8°44′E). The 2-meter animal did not differ in color pattern from spotted porpoises of the eastern tropical Pacific. Fraser thought the specimen to be unique in its white snout tip. As I have demonstrated (Perrin, 1970*a*), this feature is an aspect of individual and/or among-school variation and occurs in spotted porpoises around the world. Other discrepancies noted by Fraser between the color patterns of this animal and those of *Stenella frontalis, S. froenata, Clymene punctata,* and various specimens from the eastern Atlantic referred to these and other species on the basis of coloration and/or skeleton, can be laid to ontogenetic variation (see Perrin, 1970*a*) and/or inadequacy of early descriptions and illustrations.

Fraser classified the specimen on the basis of cranial characters, in the process accomplishing an exhaustive review of relevant museum materials. He eliminated the types of *Delphinus plagiodon* and *Prodelphinus graffmani* Lönnberg from consideration because of large size, and *Delphinus clymene* Gray (= *Clymene normalis* Gray) because of very small posttemporal fossae. This left 31 skulls (15 from known localities), including the types of *Clymenia doris, Delphinus froenatus* (including the skull considered by G. Cuvier to belong to *D. dubius* G. Cuvier), *D. frontalis, Steno attenuatus,* and *S. capensis.* He divided this series of skulls into two groups on the basis of a dichotomy in the ranges of several measurements expressed as percent of condylobasal length. He provisionally assigned the groups to *S. attenuata* (Gray) and *S. frontalis* (G. Cuvier), making the two species sympatric in the eastern Atlantic. This division was close to that arrived at by True (1889); Fraser placed *D. froenatus* in the synonymy of *S. frontalis.* He later, however, obtained 39 skulls "remarkably similar in their general appearance and measured proportions" from Saint Helena (Fraser, 1966) that bridged the dichotomy and threw the situation back into its original long-standing state of confusion (Best, 1969).

Hershkovitz (1966) followed Fraser (1950). But he revived *Stenella dubia* (= *Delphinus dubius* G. Cuvier) on the basis of Fraser's tentative association of skulls labeled as such in the Paris Museum with the *S. frontalis* group. Rice and Scheffer (1968) recognized only a single species of spotted porpoise worldwide, *S. dubia,* on the basis that "Rice has seen in a single school animals showing all described color variations; no consistent cranial differences have been described."

Density and distribution of spots demonstrably vary ontogenetically and geographically within single species (Perrin, 1970*a*, and section below on coloration). Other elements of color pattern, however, are remarkably constant within recognized delphinid species and species groups. In all bottlenose porpoise (*Tursiops* spp.), the flipper band runs from flipper insertion to eye. In all "common dolphins" (*Delphinus* spp.), the flipper band runs to the gape, and there is a distinctive crisscross effect on the midlateral body, induced by overlap of the cape and ventral field (Perrin, 1972*b*). In the spinner porpoises the band runs to the eye as in *Tursiops* (Perrin, 1972*b*), and section on spinners below). Based on this state of affairs in better-known animals, there would seem to be two species of spotted porpoise in the Atlantic. First, there is a large form of relatively low variability in the western Atlantic, Gulf of Mexico, Caribbean, and possibly eastern Atlantic (Cadenat, 1959). In this species, the flipper band runs to the eye, as in *Tursiops* and the spinners, and there is a spinal blaze (terminology of Mitchell, 1970). This form has commonly been referred to *S. plagiodon* (Cope), on the basis of True's 1889 decision. Second, a form more variable in size and spotting occurs throughout the tropical and sporadically in the warm temperate Atlantic. In this species the flipper band runs to the gape, as in the eastern Pacific spotted forms (Perrin, 1970*b* and above) and in the types of *S. pernettyi* (Desmarest), *S. frontalis* (Dussumier, in G. Cuvier, 1829) and *S. froenata* (F. Cuvier in St. Hillaire, 1829). All clear illustrations and unpublished photographs that I have seen of spotted porpoise from other parts of the world show the flipper band extending to the gape, indicating that first species mentioned above may be limited to the Atlantic. Both these distinct forms may be seen in Mitchell (1970), as "*Stenella plagiodon*" and "*Stenella* sp.," respectively. There are indications that the forms overlap in their geographical ranges but are found in different habitats (Caldwell and Caldwell, 1966; Caldwell et al., 1971). Schmidly, Beleau, and Hildebran (1972) referred animals from the same area of the Gulf of Mexico to both *S. plagiodon* and *S. frontalis.*

Indian and Pacific Oceans

The first notice of spotted porpoise from the Indian and Pacific Oceans was a publication by Lesson in 1826 of the description of the species *Delphinus malayanus* from the area between Java and Kalimantan. He described a harpooned specimen as uniformly ashy gray with a deep furrow at the base of the snout. The figure of the 5′11″ specimen is extremely crude and appears to have been the basis for the written description. The figure is distorted, in that the caudal dorsal ridge (present in all delphinids) if extended anteriorly would run to the gape. The written description compounds this clumsy distortion by saying, “*Une forte carêne, comme celle de certains scombres, occupait les parties latérales et postérieures du corps.*” Despite the general low quality of the account and the (in my opinion) nonidentifiable figured specimen, subsequent workers (True, 1889, and Trouessart, 1898, among others) have considered the description valid and held the name to be the senior synonym for animals of the spotted type from the area. Lesson repeated the written description in his 1828 book but added no new details. G. Cuvier in 1829 published his suspicion that *D. plumbeus* G. Cuvier is the same as *D. malayanus.* Schlegel (1841) referred four specimens from Southeast Asia (a young specimen from Kalimantan, the skull of an old animal from Sulawesi, and two incomplete skulls from Java) to *D. malayanus* and concurred with G. Cuvier about *D. plumbeus.* He also stated that in his opinion *D. dubius* G. Cuvier should also be considered the same animal, making the range of tooth count 30 to 40. The illustrated skull, with $\frac{37}{38}$ teeth and without the “für *D. delphis so charakteristischen tiefen Hohlkehlen auf beiden Seiten der unteren Fläche des Oberkiefers*” is certainly very similar to that of the described species from the Atlantic (and the offshore spotted porpoise of the eastern Pacific). Whether this is the same species dealt with by Lesson, of course, must remain unknown.

Pucheran (1856*a*, 1856*b*) later separated *D. plumbeus* (= *Sotalia plumbea*) from the spotted porpoise.

The “female dolphin No. 2” captured by Dussumier on April 4, 1828, at 32°S lat, 51°E long (about 400 miles south of the Malagasy Republic), and depicted by him in a watercolor sketch that was unpublished until very recently (Arvy, 1972) appears to have been a spotted porpoise, with a stripe from flipper to gape.

G. Cuvier (1829) described *D. velox* from Sri Lanka, with “*le museau un peu plus alongé* [than *D. dubius*], *et partout quarante-une dents.*” F. Cuvier (1829, in St. Hillaire) expanded the description of “*le Dauphin Leger No. 2,*” stating that it was collected by Dussumier between Sri Lanka and the Equator, that it had 40 teeth in each jaw, was 4′ 9″ long and was thus colored “*noir en dessus, et d’une teinte verdâtre très-foncée en dessous, avec des marbrures noires* [black mottling].” His figure shows a dark gray animal with long, well-defined snout and falcate dorsal fin. These features, the tooth count, and ventral mottling connect the specimen with the spotted porpoise.

Hombron and Jacquinot (1842-1853) described and figured an animal from the Straits of Banda, Singapore (fide Gray, 1850) that they called “*dauphin à petits pectorals.*” Wagner (in von Schreber and Wagner, 1846) published an external figure of the animal and labeled it *Delphinus brevimanus*, with no explanation in the text. Gray (1950) based

Delphinus ? *microbrachium* on the skull in the Paris Museum of what presumably was the same specimen, citing Hombron and Jacquinot. Jacquinot and Pucheran in Hombron and Jacquinot (1853), redescribed the species (as *D. brevimanus* Wagner), illustrating external appearance and skull. As True (1889) noted, in the figure the flippers are entirely too small. Their shriveled appearance and the presence of wrinkles in several places suggest that the illustration was prepared from the stuffed skin in the Paris Museum, perhaps accounting for the complete lack of color pattern. The skull is that of a spotted porpoise. Flower (1884) stated that it is "not distinguishable from others [in the Paris Museum] marked *D. dubius*."

Peale (1848) reported on a specimen from the Phoenix Islands (2°47′5″S, 174°13′W) and described the species *Delphinus albirostratus.* The figure and description of external appearance and the tooth counts $\left(\frac{40}{40?}\middle|\frac{40}{40?}\right)$ identify the animal as a spotted porpoise. The specimen was 6′7 1/2″ long, with a stripe from flipper to gape, and "covered with small vermicular white spots." The specimen was not saved. Cassin (1858) republished Peale's figure and placed *D. albirostratus* in the synonymy of "*Lagenorhynchus caeruleoalbus* (Meyen)" [= *D. coeruleo-albus* Meyen, 1833, definitely not a spotted species]. Dall (1874) reported on a specimen taken between Tahiti and San Francisco at latitude 13°N (if the route between Tahiti and San Francisco was a straight line or nearly so, the animal was captured in an area today part of the offshore tuna "porpoise grounds"). The animal was "gray, lighter below and darker above." He referred it tentatively to *L. albirostratus,* stating that Cassin's referral of the species to *Lagenorhynchus* was probably erroneous. The specimen is no longer in the collection of the California Academy of Sciences and was probably lost in the 1906 fire and earthquake.

True in his review of the Delphinidae (1889), included all the species and specimens of spotted porpoise known from the Indian and Pacific Oceans under *Prodelphinus malayanus* (Lesson), except Dall's specimen of *Lagenorhynchus* ? *albirostratus* which he referred to *P. doris* Gray on the basis of skull measurements. He left Peale's specimen in a list of species *incertae sedae.* Later (1894), however, True referred five specimens from the Indian Ocean (two from the Amirante Islands, and one each from Alphonse, Providence, and Johanna Islands, in the Seychelles) to *Prodelphinus attenuatus* (described by Gray in 1846 from a specimen from an unknown locality) on the basis of the spotted coloration that linked them to *Clymene punctata* Gray (described from Cape Verde), which species he had earlier placed in the synonymy of *P. attenuatus* on the basis of cranial characters. True in 1906 referred two specimens of spotted porpoise from Hawaii to *P. attenuata.* These two specimens are included below in the sample of Hawaiian specimens compared to the eastern Pacific series.

Hector (1885) referred a skull and mandible from New Zealand waters to *Clymene attenuata* Gray. Oliver (1922) later referred the specimen to "*Stenella pseudodelphis* Schlegel, 1841" [= *Delphinus pseudodelphis* Wiegmann in von Schreber and Wagner, 1846]. True had considered *D. pseudodelphis* a nomen nudum. Weigmann (loc. cit.) published only a figure of a skull, with no description, antedating *Steno attenuata* Gray. Baker and Stephenson (1972) subsequently referred the New Zealand specimen to *S. dubia* (G. Cuvier, 1812).

In recent years, several authors have reported on spotted porpoise from Japanese waters, each referring the animal to a different species. Ogawa (1936) described a specimen from Nagasaki and referred it to *Prodelphinus froenatus* (F. Cuvier). The photograph shows an animal with a distinct band from flipper to gape and a cape pattern similar to that of the eastern Pacific animals. Spots are not evident in a photostat of the published photograph. Mizue and Yoshida (1962) described three specimens, called *madara iruka,* from Goto Island, Nagasaki Prefecture, and stated they were the same as Ogawa's specimen but probably not "*Prodelphiuus froeuatus* [*sic*]." Again, the color pattern as shown in the photographs differs from that of the eastern Pacific animals only in intensity of spotting. Nishiwaki, Nakajima, and Kamiya (1965) very thoroughly documented a school of about 50 spotted porpoise captured by "oikomi drive" at Arari. They felt that they, "although most resembling *Stenella attenuata*" belonged to an "independent species." In the title of the paper, and in Nishiwaki (1966), the animals were referred to *S. attenuata.* The excellent photographs of these specimens show an animal with color pattern nearly identical to that of far offshore eastern Pacific animals (compare with figure. 5), again differing only slightly in density and size of spots. In his 1965 book (with Yabuuchi) and 1972 review, Nishiwaki recognized both *S. attenuata* and *S. frontalis* (Ogawa's and Mizue and Yoshida's specimens) from Japan.

Dawbin (1966) reported spotted porpoise from the Solomon Islands and referred them to the "*frontalis-attenuata* group." Best (1969) reported on a specimen from off Durban, South Africa, in the Indian Ocean. He referred it to *S. attenuata.*

Prior to studies begun in 1968 by the United States government on the tuna-porpoise association, knowledge of the distribution of spotted porpoises in the eastern Pacific was very scanty. The supposedly endemic spotted *Prodelphinus* (= *Stenella*) *graffmani* Lönnberg, 1934, had been described from off Acapulco. Van Gelder (1960) reported on single skulls from the Tres Marias Islands and from "8 miles southwest of Maldonado Point, Oaxaca, " Mexico. Hershkovitz (1966) listed the range of *S. graffmani* as "eastern Pacific, from Acapulco, Guerrero, Mexico, south, following the coast to Panama and Isla Gorgona off the western coast of Colombia" (localities listed in addition to the type locality are of specimens in the U.S. National Museum). Nishiwaki (1967) published a chart showing *S. graffmani* having an offshore distribution extending from approximately 28°N latitude to the equator and west to approximately 150°W longitude. This chart was based in part on sight observations by crews of Japanese longline fishing vessels (personal communication from M. Nishiwaki).

In the Indian and Pacific Oceans, then, are populations of spotted porpoise off South Africa, in the Seychelles, probably near Sri Lanka, in Malaysian waters, in the Solomons, in Japanese waters, in the South Pacific, in Hawaiian waters, and in the eastern tropical Pacific. All are very similar to each other and to Atlantic specimens in cranial features, all having a flipper-to-gape stripe (like one of the two apparent species in the Atlantic), and differing between each other mainly in intensity of spotting. Most workers have followed True's (1894 and 1906) lead and referred the central and western Pacific animals to *S. attenuata.* Hershkovitz (1966) referred them to *S. dubia,* with *S. attenuata* in synonymy. Rice and Scheffer (1968) placed all spotted porpoise everywhere in *S. dubia.* This move was ill advised, because, as discussed above, there would appear to be at least two species in the Atlantic.

VARIATION

Coloration

Very few accurate descriptions or photographs of color pattern exist for any cetacean, including the species of *Stenella*. Two photographs of spotted porpoise from the eastern tropical Pacific were published before 1968. A photograph included in Lönnberg's (1934) description of *Prodelphinus graffmani* showed the skin of the type specimen, mounted after preservation by salting. A photograph in Walker (1964) under *Stenella graffmani* is of a dead specimen from an unspecified location in the eastern Pacific. In both specimens, postmortem darkening has obviously progressed to the point of obliteration of most of the color pattern.

My direct knowledge of coloration of the spotted porpoises in the eastern Pacific is limited the form involved in the tuna fishery. I have previously documented and discussed variation owing to development, individual variation, and differences among schools (Perrin, 1970*a*).

Sexual Dimorphism

Spotted porpoise of the eastern Pacific are not sexually dimorphic in coloration. In describing the color pattern of *Stenella attenuata*, a nominal form very similar in coloration to spotted porpoise in the eastern Pacific (Perrin, 1970*a*), Nishiwaki (1972) stated that in females "the skin around the mamilla is slightly lighter in color" than in males. In an effort to ascertain whether such a dimorphism exists in spotted porpoise from the eastern Pacific, I examined photographs of 20 specimens (10 males and 10 females), five harpooned inshore and 15 from the tuna fishery. Of these, five females and two males had noticeable mottling or lightening of the skin in the genital region. Nishiwaki did not state his sample size, but there seems to be no consistent difference between males and females in this feature in the eastern Pacific. Nor does inspection of photographs reveal dimorphism in any other element of the color pattern.

Geographical Variation

Dorsal spotting varies widely among adult individuals (Perrin, 1970*a*) and diminishes as one moves westward within the eastern Pacific. This continuum can be broken up into arbitrary increments, as follows:

1. Heavy spotting – Spots so large and numerous as to give mottled or nearly white appearance in dorsal view. Extensive merging of spots over eye and on posterior half of peduncle, with some merging overall.
2. Medium spotting – Spots numerous and obvious. Some spots merge above the eye and on dorsal side of posterior half of peduncle.
3. Sparse spotting – Spots so small and so few as to make spotting almost obscure. All spots discrete.

I rated 107 specimens by these criteria (table 3). Ten were animals observed or harpooned within a few miles of the coast of southern Mexico, of which I examined only photographs. The remaining 97 were from the tuna fishery, and I examined them fresh at sea or in a frozen state ashore. Ninety were taken from 50 to 500 miles offshore, and seven are from farther offshore, to 133°W longitude (generally outside a line joining the Revilla Gigedo Islands, Clipperton Island, and Cocos Island.

Table 3. Intensity of spotting in three geographical series of spotted porpoise

Area	Sample	Dorsal Spotting		
		Heavy	Medium	Sparse
Coastal	10	6(60%)	3(30%)	1(10%)
Offshore	90	61(68%)	61(68%)	13(14%)
Far offshore	7	0	4(57%)	3(43%)

Spotting tends to be heaviest in the easternmost, coastal animals (Perrin, 1970*a*) and sparsest in the westernmost, most offshore animals (fig. 5). Compared to the coastal animals, the offshore animals also are lighter and more mottled in the ventral area below the cape, yielding a sharp contrast with the cape.

The coloration of the Hawaiian form continues the east-west trend. The best published photograph of a Hawaiian spotted porpoise, or "Keiko," is in a *National Geographic* article by Conly and Nebbia (1966:414). Comparison of this photograph with that of an animal (fig. 5) from the westernmost part of the offshore range of the spotted porpoise in the eastern Pacific demonstrates the essential identity of the two forms. The pattern on the head is not apparent in young animals (fig. 6 and photograph on p. 40 of Stenuit, 1968; compare with photographs in Perrin, 1970*a*). The differences in coloration among the spotted porpoises from Hawaii and the offshore and inshore eastern Pacific are of degree, not of kind (fig. 7). Contrast between cape and lateral field is greatest in the Hawaiian animals and least in some of the animals from the far eastern Pacific. Spotting is most intense in the far eastern Pacific and least in Hawaii. Discrete ventral dark spots are present temporarily on the snout and between the gape and flippers during development (fig. 6, and drawing and description of animal in True, 1906); but ventral mottling in adults owing to convergence of the spots, while present, is in most animals so obscure as to appear nearly absent. Dorsal light spots are absent or sparse in all specimens and photographs that I have seen of Hawaiian animals. Animals to the south and west of Hawaii are spotted dorsally (Peale, 1848; Dawbin, 1966; personal communication from K.S. Norris). In all other features of the color pattern there are no differences among the forms.

External Morphology

Few data have been published on the external proportions of spotted porpoise from the eastern Pacific. Lönnberg (1934) included a set of external measurements in his description of the type specimen of *S. graffmani* (2245 mm total length) from a stuffed, salted skin. Other workers (Boice, Swift, and Roberts, 1964; Daugherty, 1966; Harrison, Boice, and Brownell, 1969*b*; Pilson and Waller, 1970) have published measurements of total length ranging from 75 cm to "8-foot[244 cm]."

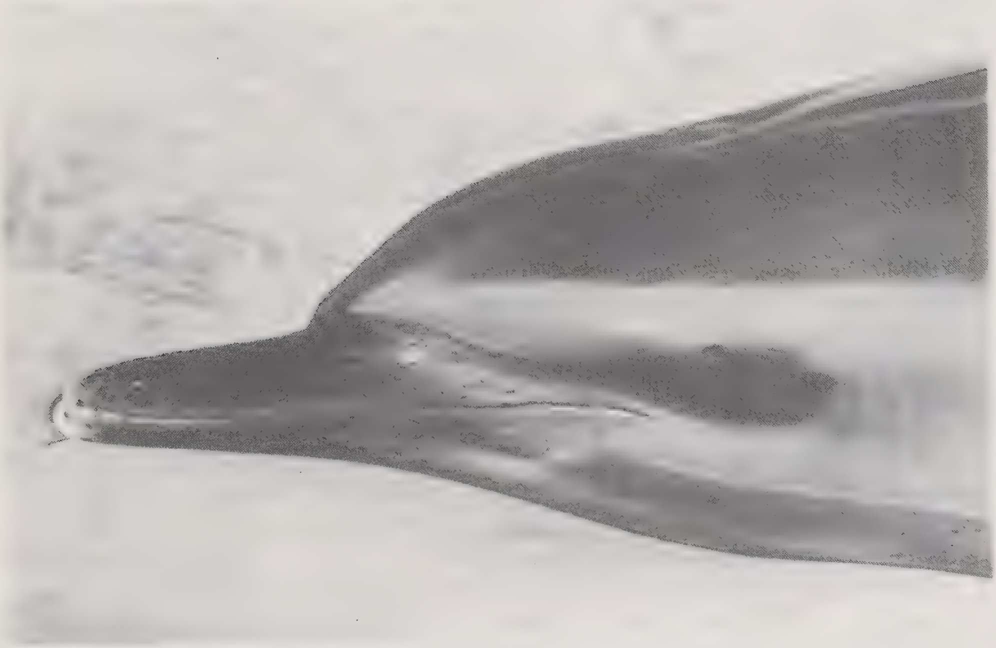


Figure 6. Young Hawaiian spotted porpoise.

Development

Body proportions change markedly during ontogeny. The analyses are based on measurements of 214 spotted porpoise collected in the tuna fishery.

Growth is heterogonic (fig. 8). Changes in proportions during early postnatal development result primarily from a decreasing rate of growth of the head (snout excepted) relative to that of the torso, combined with an early surge in growth of the snout. Later change in proportion results from continued growth of the torso between the umbilicus and anus. Changes in proportions between birth and maturity are similar to those in *Globicephala* as determined by Sergeant (1962), except that the flippers and dorsal fin become proportionately smaller rather than larger.

To analyze developmental patterns and to provide criteria for deciding which specimens should be included in a consideration of variation in the adults and near adults, the measurements were plotted against total length. Where sexual dimorphism is indicated, males and females were considered separately. Selected graphs (fig. 9 and 10) illustrate the major patterns of growth.

The measurements can be divided into two groups: those for which the relationship between the measurement and total length appears linear and those for which it is nonlinear (table 4). For some measurements, the mode of increase is different for males and females. For those measurements in which the relationship between measurement and total length appears linear, that is, for which the value of α in Huxley's (1932) general growth equation, $Y = a + bX^{\alpha}$, is 1, the equation of the least squares regression line is

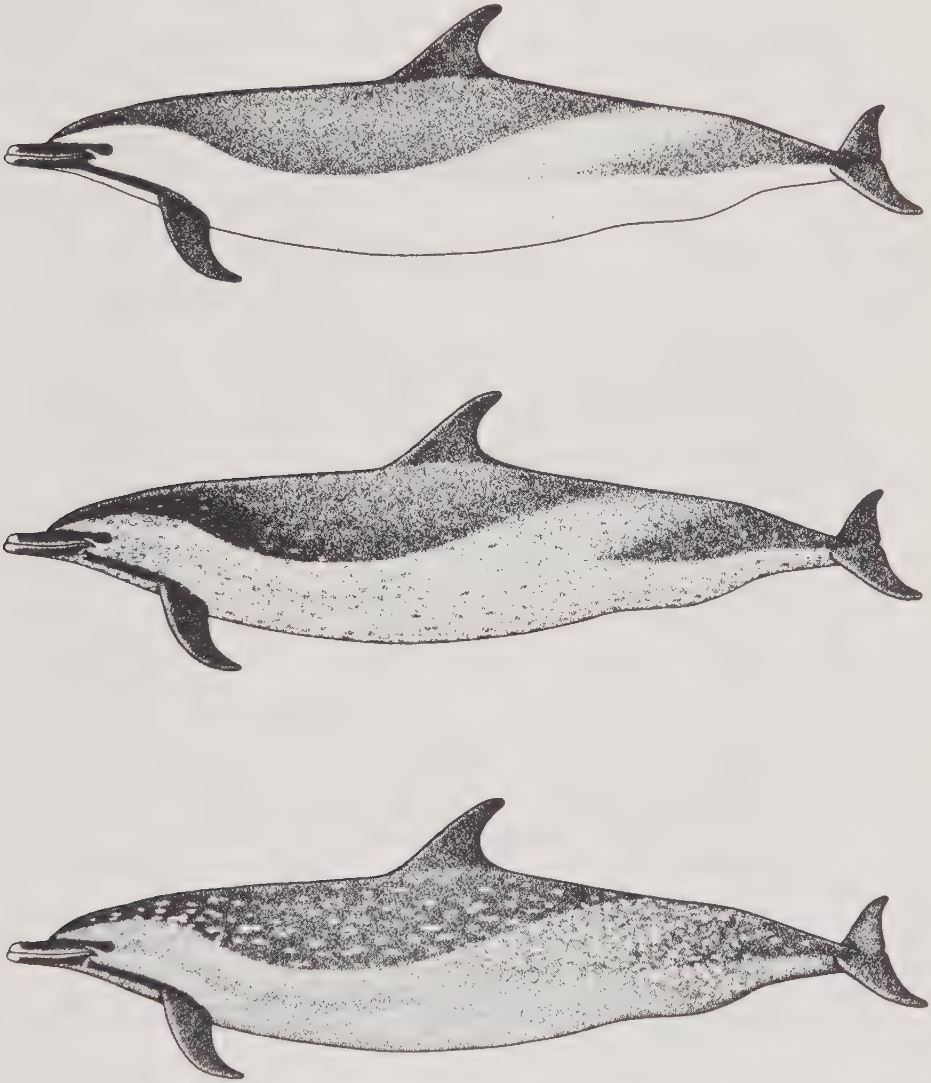


Figure 7. Variation in color pattern of spotted porpoise: (top) Hawaiian, (middle) far-offshore eastern Pacific, (bottom) offshore and coastal eastern Pacific.

included in table 4. For these linear cases, the sign of the Y-intercept of the regression line provides an index to mode of growth. If the intercept is zero, growth has been completely isometric throughout development. If it is positive, growth is negatively allometric; if negative, positively allometric.

Allometric growth entails an exponential relationship between parts. For this reason, the linear model is not appropriate for the data for the complete span of postconceptual development for the measurements where the intercept is not equal to zero. Where data

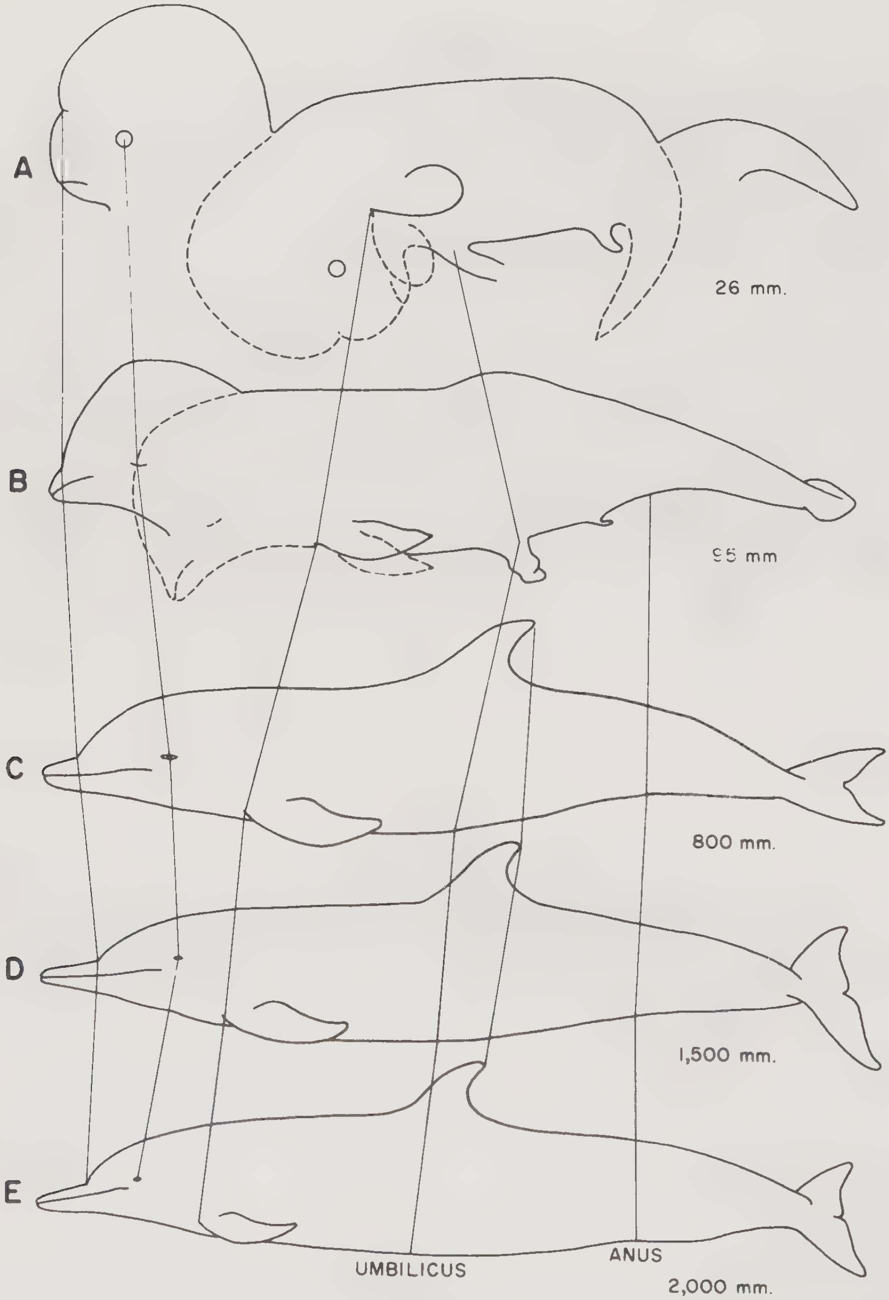

A
26 mm.
B
95 mm
C
800 mm.
D
1,500 mm.
E
UMBILICUS
ANUS
2,000 mm.

Figure 8. Ontogeny of external proportions of spotted porpoise, drawn from specimens. A. Fetus of *Stenella coeruleoalba* (after Sinclair, 1967). B. Fetus of spinner porpoise. C, D, and E. Postnatal specimens of spotted porpoise. The specimen of *S. coeruleoalba* and the spinner fetus are included in the series because it is felt that interspecific differences are probably insignificant during very early development.

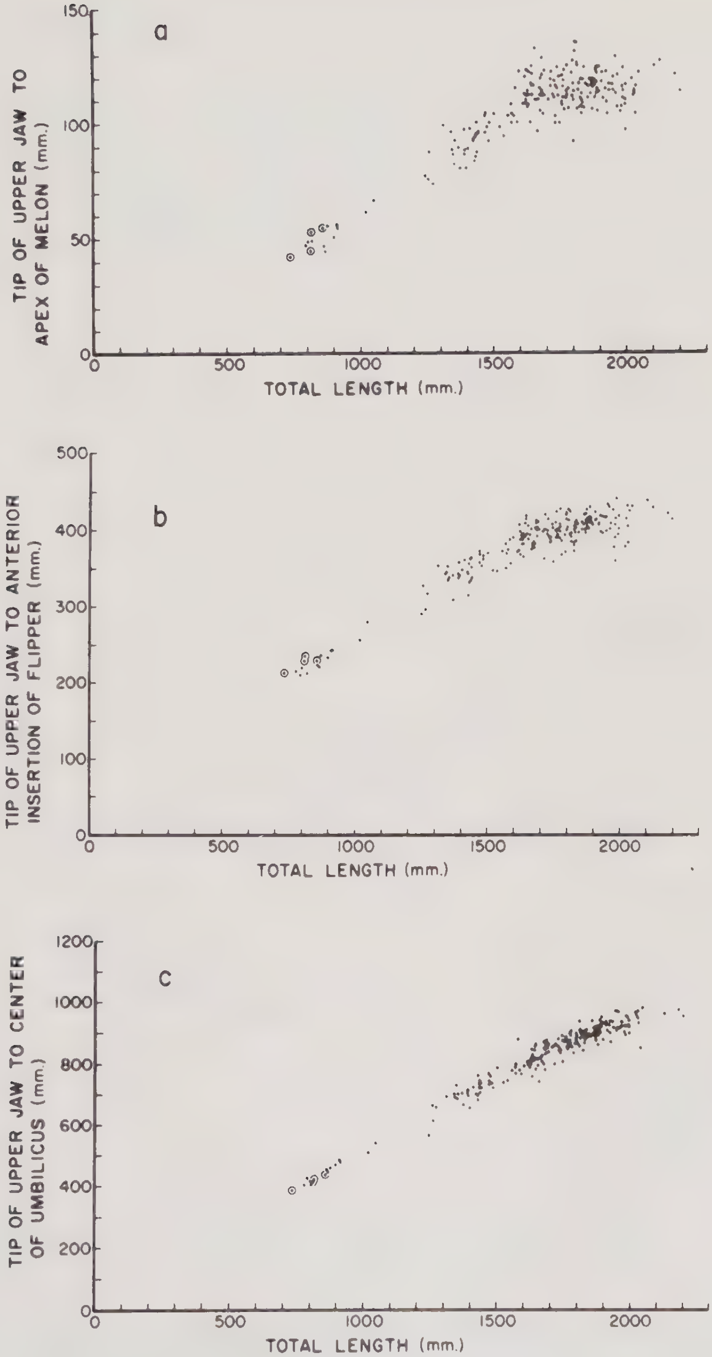


Figure 9. External development of spotted porpoise: scatterplots of external body measurements against total length, demonstrating changing proportions. Circles represent fetal specimens (continued).

are available only for a limited segment of the span of development, however, the linear model provides sufficiently good fits to allow comparison of measurements and of growth patterns.

After the linear instances have been considered, most of the remaining measurements show a similar pattern of increase and variation relative to total body length. They have a linear relationship with total length until approximately 1600 mm, after which they increase much less rapidly, if at all, and exhibit larger variance. These include the long measurements of the anterior portion of the body, the measurements reflecting anterior

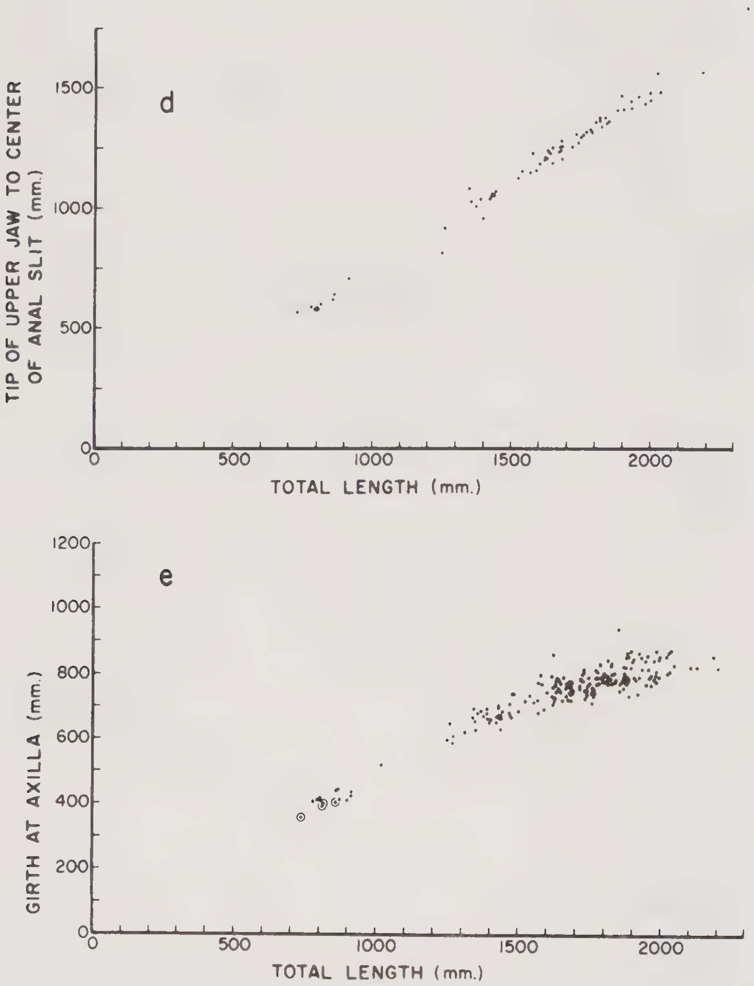


Figure 9 (continued). External development of spotted porpoise: scatterplots of external body measurements against total length, demonstrating changing proportions. Circles represent fetal specimens.

robustness, and those of dimensions of the flippers and the dorsal fin. This trend is perhaps best shown in the measurement of the rostrum (fig. 9a), and is least pronounced in the measurement from tip of upper jaw to tip of dorsal fin. The inflection in the curves at length of about 1600 mm corresponds roughly to the onset of puberty. The inferred pattern of growth is as follows: the length and breadth of the head, anterior girth, and dimensions of the flippers and dorsal fin grow allometrically after birth at a constant rate relative to growth in total body length until the onset of sexual maturity. Afterward they grow more slowly and at a rate that varies greatly between individuals. As noted above (table 4), span of the flukes, as well as distance of the external ear from the center of the eye and, in females, girth at the anus, continue to grow at the same rate relative to growth in total length as in smaller animals. The measurements reflecting relative positions of the genital aperture and anus also increase in this manner. This pattern of growth of the flukes was also found for *Globicephala melaena* by Sergeant (1962).

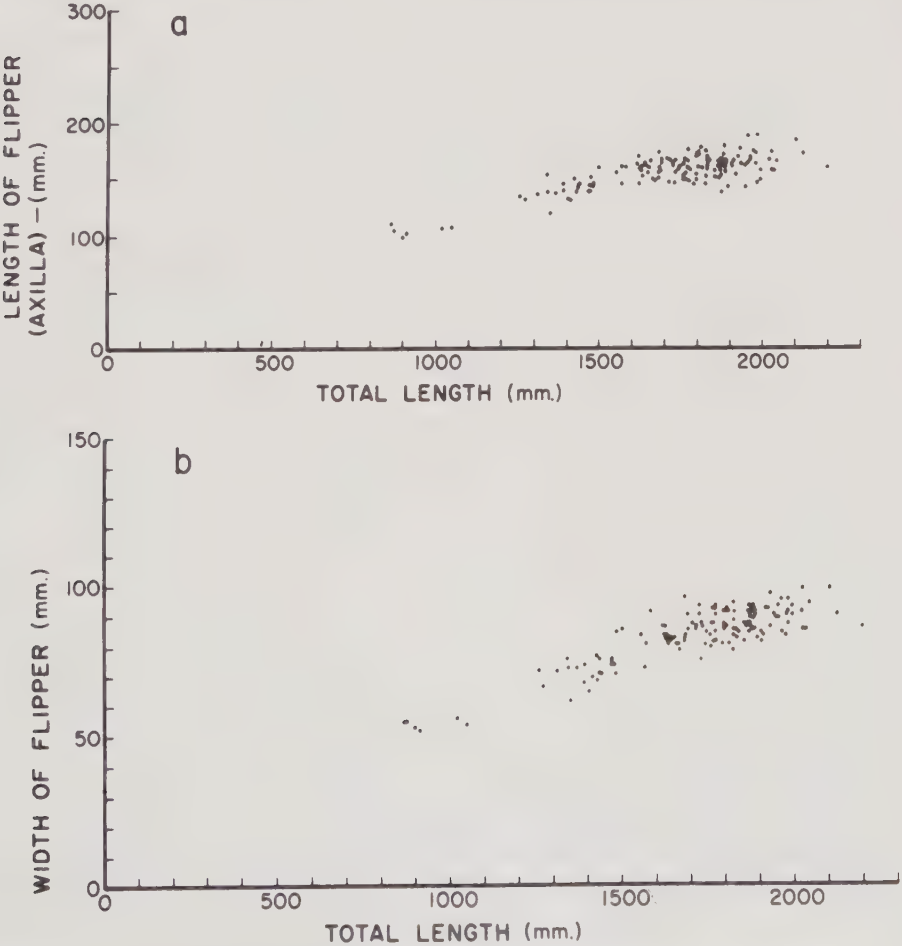


Figure 10. External development of spotted porpoise: scatterplots of appendage measurements against total length, demonstrating changing proportions (continued).

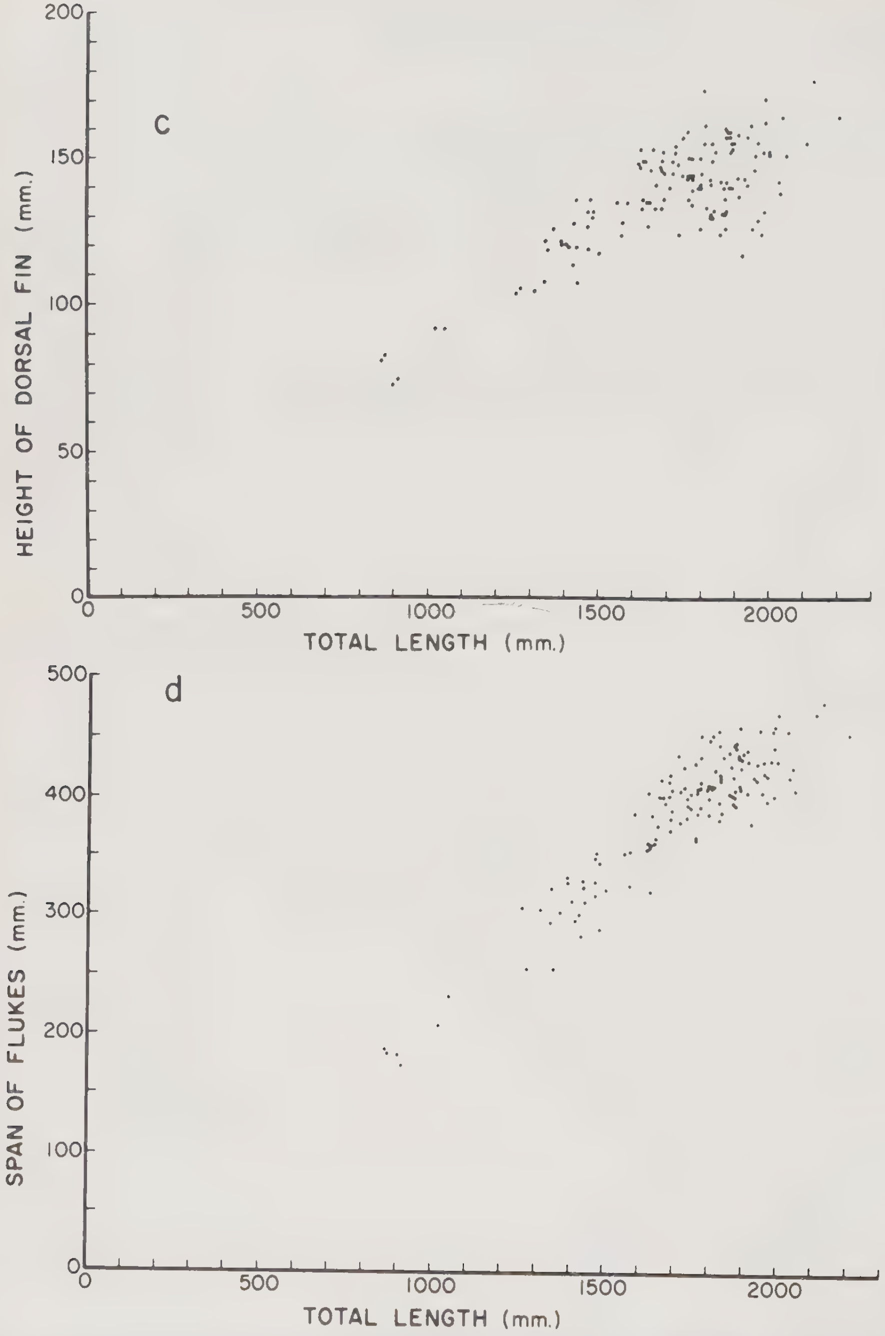


Figure 10 (continued). External development of spotted porpoise: scatterplots of appendage measurements against total length, demonstrating changing proportions.

Girth at the anus in males also shows a change in rate, but of a different sort, and is discussed in the section below on sexual dimorphism.

Progress has been made in developing a method to determine the age of tropical delphinids (see Methods above), and age-correlated data have become available for subsample of the specimens included above. The results obtained in analysis of selected measurements for this subsample do not modify the conclusions reached above. Total length (fig 11a) continued to increase in postpubertal animals (> 160 cm, ⩾ 4 layers), with some dimensions such as snout to anus (fig 11b) keeping pace (the linear instance above), but anterior dimensions, especially length of the snout (fig 11c) level off sharply and show no correlation with age (or total length) in adults (the curvilinear specimen above).

Sexual Dimorphism

The patterns of development of some external dimensions are sexually dimorphic. Although girth at the anus in females increases at the same rate throughout development after birth, in males it increases more rapidly after total length of about 160 cm is reached. Dimorphism is also evident in a plot of girth at anus against number of dentinal layers (fig. 11d). Girth at the anus is on the average greatest in the oldest individuals, and sexual dimorphism is very apparent in large adults (> 10 layers, ⩾ 180 cm total length). In lateral view, an adult male (fig. 5) shows a slight vertical thickening of the caudal stock just behind the anus. This dimorphic feature is more exaggerated in spinner porpoises than in spotted porpoises. I have previously discussed its possible function as a signal for species recognition in mixed schools (Perrin, 1972). Although the genital aperture occupies a progressively more forward position during postnatal growth, it is placed farther forward in the male than in the female; the disparity increases with development.

Dimorphism is present in adults. Adulthood was defined on the basis of examination of gonads. All 9 males over 180 cm total length for which histological examination of the testes were carried out exhibited spermatogenesis. The smallest sexually adult female encountered was 173 cm long (with a single corpus of ovulation). At least one of the ovaries of each of all females over 175 cm (except two, 177 and 183 cm long) contained corpora albicantia or a corpus luteum. These findings were used as a basis for splitting the large sample of specimens for which external measurements (but no histological examinations of gonads) were made into two groups, those males larger than 180 cm and females 175 cm long or longer, supposedly sexually adult, and the smaller animals, supposedly immature. A summary of the results (table 5) indicates that for adult males the total length is greater; the eye and external auditory meatus are farther apart; the distances from snout to dorsal fin, umbilicus, and anus are greater; the girth at the axilla is greater; the girth at the anus is greater (both absolutely and proportionately); and the flipper is wider than in adult females. In adult females, however, the dorsal fin is more posterior, girth at the axilla is proportionately greater, and fluke span is proportionately greater than in adult males. It must be remembered, however, that a large number of

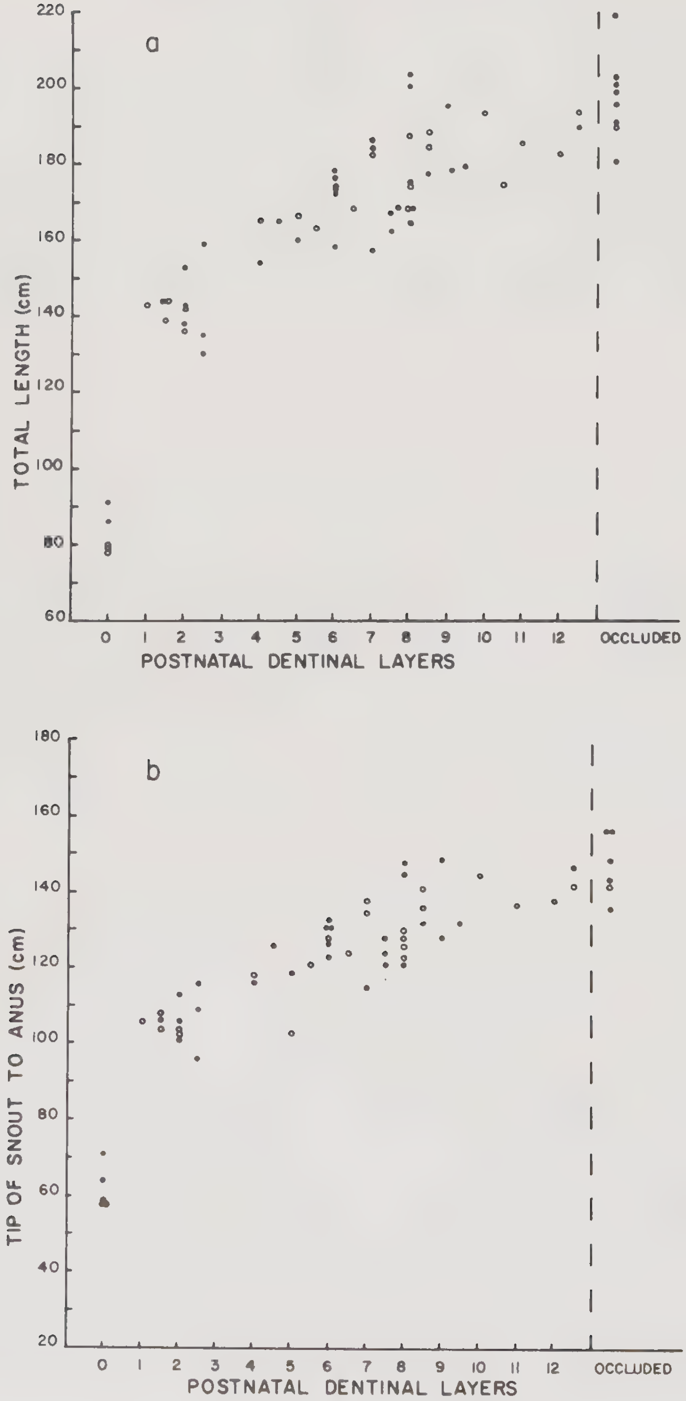
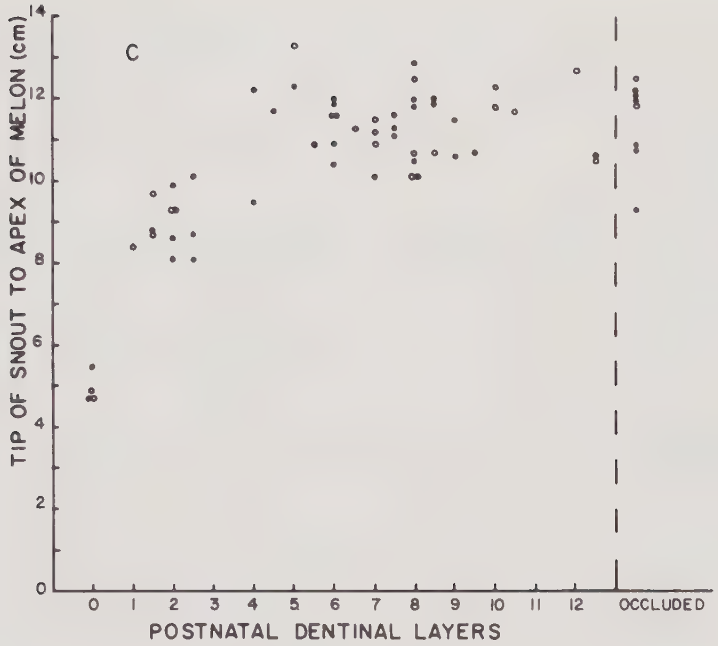


Figure 11. External development of spotted porpoise: scatterplots of external measurements on number of postnatal deninal layers (continued).



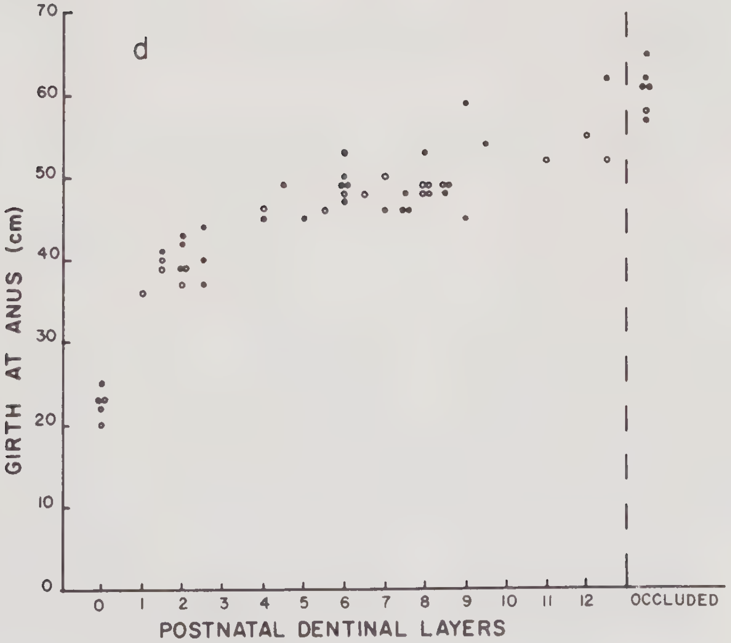


Figure 11 (continued). External development of spotted porpoise: scatterplots of external measurements on number of postnatal layers.

Table 4. Mode of increase of measurements relative to total length of spotted porpoise

Measurement	Mode of increase relative to total length		Equation of least squares regression line, where X = total length, Y = regressed measurement	Correlation coefficient r
	Linear	Nonlinear		
Tip of upper jaw to center of eye		+		
Tip of upper jaw to apex of melon		+		
Length of gape		+		
Tip of upper jaw to external auditory meatus		+		
Center of eye to external auditory meatus	+		$Y = 18.5\text{ mm} + .017\,X$	.93
Center of eye to angle of gape		+		
Center of eye to center of blowhole		+		
Tip of upper jaw to blowhole		+		
Tip of upper jaw to anterior insertion of flipper		+		
Tip of upper jaw to tip of dorsal fin		+		
Tip of upper jaw to midpoint of umbilicus		+		
Tip of upper jaw to midpoint of genital aperture: Males	+		$Y = 53.3\text{ mm} + .627\,X$	.98
: Females	+		$Y = -16.8\text{ mm} + .719\,X$	.99
Tip of upper jaw to center of anus	+		$Y = 9.38\text{ mm} + .751\,X$	.99
Girth at axilla		+		
Girth at anus: Males		+		
: Females	+		$Y = -15.3\text{ mm} + .290\,X$	.99
Length of flipper, axilla to tip		+		
Width of flipper		+		
Height of dorsal fin		+		
Span of flukes	+		$Y = 3.4\text{ mm} + .228\,X$	.92

Table 5. External measurements of adult male and female offshore spotted porpoise

Measurement	Males					Females					Absolute value of significant t, at $\alpha = .05$	
	Number of specimens	Range (mm)	Mean (mm)	Standard deviation (mm)	CV (100 s/$\bar{x}$)	Number of specimens	Range (mm)	Mean (mm)	Standard deviation (mm)	CV	Absolute	Percentage of total length
Total length	34^{a}	1801-2200	1965	96.2	4.90	59^{a}	1750-2128	1860	68.7	3.69	8.36	
Tip of upper jaw to center of eye	34^{a}	269-327	297	11.7	3.94	59^{a}	273-330	299	10.8	3.61		
Tip of upper jaw to apex of melon	33^{a}	93-136	115	8.6	7.48	59^{a}	101-136	117	6.8	5.81		
Length of gape	34^{a}	238-290	254	12.6	4.96	59^{a}	223-283	255	10.7	4.20		
Tip of upper jaw to external auditory meatus	9^{c}	317-355	340	12.9	3.79	10^{c}	331-349	342	5.5	1.61		
Center of eye to external auditory meatus	9^{c}	51-55	53	1.6	3.02	10^{c}	46-53	50	2.4	4.80	4.15	
Center of eye to angle of gape	9^{c}	43-56	48	4.6	9.58	11^{c}	44-52	49	2.6	5.31		
Center of eye to center of blowhole	33^{a}	114-136	124	4.5	3.63	59^{a}	108-134	122	5.1	4.18		
Tip of upper jaw to blowhole	33^{a}	258-325	295	13.2	4.47	59^{a}	271-324	297	11.5	3.87		
Tip of jaw to anterior insertion of flipper	34^{a}	370-444	413	18.2	4.41	59^{a}	363-446	410	15.5	3.78		
Tip of upper jaw to tip of dorsal fin	32^{a}	1053-1219	1129	44.5	3.93	58^{a}	1020-1229	1105	46.2	4.18	4.04	5.38
Tip of upper jaw to midpoint of umbilicus	33^{a}	852-988	927	33.2	3.58	58^{a}	809-974	904	31.8	3.52		
Tip of upper jaw to midpoint of genital aperture	9^{c}	1208-1378	1301	50.8	3.90	11^{c}	1246-1393	1324	41.6	3.14	18.56	
Tip of upper jaw to center of anus	9^{c}	1361-1570	1479	63.3	4.28	11^{c}	1303-1452	1384	41.0	2.96	4.98	
Girth at axilla	31^{a}	768-970	814	35.0	4.30	52^{a}	711-934	794	39.6	4.99	4.02	3.40
Girth at anus	8^{c}	531-652	600	37.8	6.30	9^{a}	488-580	520	30.6	5.88	6.30	2.59
Length of flipper, axilla to tip	25^{b}	144-190	166	10.1	6.08	48^{b}	139-189	162	10.4	6.42		
Width of flipper	25^{b}	84-100	91	4.3	4.73	48^{b}	79-98	88	4.6	5.23	3.99	
Height of dorsal fin	24^{b}	124-173	146	13.5	9.25	48^{b}	117-176	145	12.5	8.62		
Span of flukes	24^{b}	397-473	430	24.2	5.63	48^{b}	366-491	421	26.1	6.20		2.05

[a] Includes specimens from all collections.

[b] Frozen specimens not included.

[c] Frozen specimens only. These measurements were not made at sea.

simultaneous *t*-tests will produce some erroneously "significant" values owing to chance alone (about 1 in 20 at $\alpha = 0.05$). Therefore, only the higher significant *t*-values, for example, for total lengths and for the girths, can be considered to indicate well-confirmed dimorphism. This same caveat applies to the other uses of long series of *t*-tests in the various tables below.

Individual Variation

Of the long measurements containing the rostrum, length of snout (tip of upper jaw to apex of melon) is most variable. Most of the variation in the other long measurements can be laid to variation in snout length.

The length of the dorsal fin shows great variation among individuals. It is more variable than the length or width of the flipper or the span of flukes, which are about equally variable.

Geographical Variation

Very few external measurement data exist for the spotted porpoise from the eastern Pacific, outside of those collected during this study of animals in the tuna fishery. It is difficult to compare external measurements taken by different observers if the methods of measuring are not precisely specified. Lönnberg (1934) published several measurements taken from the mounted skin of the holotype of *S. graffmani,* which had been preserved in salt (and presumably shrank owing to dehydration) before mounting. Total length of the holotype as thus measured was 224.5 cm, although Lönnberg stated that when freshly caught, the animal was measured by Graffman at 244 cm from snout to a line connecting the tips of the flukes. The specimen was larger than any examined for the present study of the form involved in the tuna fishery. Lönnberg stated that the external measurements made by him were taken in "straight lines" but did not specify whether they were taken point-to-point or parallel to the long axis of the body.

Skulls of spotted porpoise from near the coast are larger than those of animals from the offshore tuna fishery (see section below on variation of the skeleton). Previously unpublished data for 11 coastal specimens in addition to the very large holotype of *S. graffmani* indicate that a similar dichotomy exists in external measurements. Sample sizes of several measurements for this composite series are large enough to allow statistical comparison with the offshore series for those measurements taken on large series at sea (table 6). The measurements are converted from point-to-point to parallel-to-body axis (see Methods, above). Flipper width is not included, because my method of measurement, while aimed at defining functional width of the flipper, renders impossible conversion to the more standard "greatest width" by use of a constant coefficient.

The coastal form is larger in all the torso dimensions than the offshore form. The average length of 5 males (2060-2570 mm) exceeds the upper end of the range for the offshore series. Six females were 1999 to 2140 mm long. The divergence is greatest in tip of snout to flipper insertion, the measurement that most nearly approximates condylobasal length. There is no difference in height of the dorsal fin. There are no differences between the series in proportions, with the exception of flipper length. Flipper length to the axilla is absolutely and proportionately greater in the offshore series. This result is suspect, however, because the flipper is extremely susceptible to shrinkage from drying, and second, because the measurement varies depending on the degree to which the flipper is held away from the body while it is being measured.

External measurements of Hawaiian specimens are available for only a small sample (table 7). Statistical comparisons of means of several of the measurements with those for the offshore series are not warranted because of nonhomogeneity of variance, but it is evident that the series differ modally in several features. The series are comparable in total length; the Hawaiian series for both males (6 specimens, 1816-2021 mm) and females (3 specimens, 1890-2032 mm) lie within the ranges of the offshore series. While the series do not differ in snout length or in the long measurements to dorsal fin and umbilicus, the Hawaiian animals on the average have larger heads, as indicated by greater means for the measurements strongly affected by condylobasal length; namely, snout to eye, length of gape, snout to blowhole, and snout to flipper origin. The snout to blowhole distance also differs when taken as a percentage of total length. Fluke span does not differ between the series, but dorsal fin height is greater in the Hawaiian animals. This may be because this measurement is difficult to make in an objective manner. The point of relative size of flippers and fin will have to be elucidated in the future through comparison of measurements taken by a single investigator.

The finding based on external measurements that the Hawaiian spotted porpoise has a larger head than the spotted porpoise of the eastern Pacific agrees with the results obtained below for the skeleton.

Geographical Variation In Other Odontocetes

Several other small odontocetes have also been found to vary geographically. Variation occurs in size and other external dimensions as it does with the spotted porpoise.

Gihr and Pilleri (1969) compared measurements of 24 specimens of *Delphinus delphis* (17 males and 7 females) from the Mediterranean with those of 26 (11 males and 15 females) from the Atlantic and concluded that "the Mediterranean and Atlantic dolphins are representatives of two different races." The Atlantic form is apparently larger in total length, length of flipper, width of flipper, length of dorsal fin base, and the distance from snout tip to blowhole.

Sergeant and Brodie (1969) found marked geographical variation in the size of white whales, *Delphinapterus leucas,* over distances of only hundreds of kilometers. Extreme differences in body weight of adult males was about threefold. They distinguished three sizes of white whales in the northwest Atlantic: small whales in subarctic estuarine conditions (western part of Hudsons's Bay), medium-sized animals in arctic water having some oceanic influence (all other arctic coasts of Canada and the Saint Lawrence River), and large whales in subarctic conditions under oceanic influence (coast of West Greenland). They were able to correlate positively size with primary production (fixation of carbon) and concluded that the differences bespeak isolation of adjacent populations. The magnitude of this variation is greater than that of the coastal-offshore dichotomy in the spotted porpoise. Both instances, however, involve correlation of geographical variation with precipitously changing environmental features; namely, with productivity related to derivation of surface waters (estuarine vs. oceanic) in *Delphinapterus,* and possibly with distance from shore and/or water depth in *Stenella.*

Table 6. External measurements differing between coastal and offshore series of spotted porpoise

Measurement	Coastal (5 males, 6 females)					Offshore males					Offshore females					Absolute value of significant t, at $\alpha = .05$; test between coastal mean and closest offshore mean	
	Sample size	Range (mm)	Mean (mm)	Standard deviation (mm)	CV	Sample size	Range	Mean	Standard deviation	CV	Sample size	Range	Mean	Standard deviation	CV	Absolute	Percentage
Tip of snout to center of eye[1]	8	280-330	313	16.4	5.24	34	252-306	278	11.0	3.96	59	256-309	280	10.1	3.61	14.21	
Tip of snout to apex of melon[1]	7	119-131	124	3.9	3.15	32	91-133	112	8.4	7.49	59	98-133	114	6.6	5.82	9.19	
Length of gape[1]	7	240-280	263	14.6	5.55	34	226-276	242	12.0	4.96	59	212-269	243	10.2	4.19	9.25	
Tip of snout to blowhole[1]	7	287-305	297	6.7	2.26	33	240-303	275	12.3	4.47	59	253-302	277	10.7	3.87	13.42	
Tip of snout to anterior insertion of flipper[1]	7	410-436	428	12.6	2.94	34	343-411	382	16.9	4.42	59	336-413	380	14.4	3.78	17.81	
Tip of snout to tip of dorsal fin[1]	2M 4F	1158-1200 1119-1164				32	1000-1158	1073	42.3	3.94	58	969-1168	1050	43.9	4.18		
Tip of snout to umbilicus[1]	2M 5F	920-1000 942-991				33	839-973	913	32.7	3.58	58	797-959	890	31.3	3.52		
Flipper length to axilla	7	137-180	152	17.9	11.78	25	144-190	166	10.1	6.08	48	139-189	162	10.4	6.42	3.66	3.14

[1] Offshore data converted from point-to-point to parallel-to-long-axis (see text).

Table 7. External measurements differing statistically between series of Hawaiian and offshore (table 6) spotted porpoise

Measurements						Absolute value of significant t, at $\alpha = .05$; test between Hawaiian mean and closest offshore mean[1]	
	Sample size	Range (mm)	Mean (mm)	Standard deviation (mm)	Coefficient of variability	Absolute	Percentage
Tip of snout to center of eye	10	292-331	309	15.0	4.85	7.79	
Length of gape	9	261-290	268	12.1	4.51	6.69	
Tip of snout to blowhole	10	287-321	301	12.6	4.19	6.39	2.57
Tip of snout to anterior insertion of flipper	8	373-419	406	21.8	5.37	3.42	
Height of dorsal fin	10	133-203	166	21.3	12.83		2.48

[1] Dash indicates no test (because inappropriate, sample too small, or variance nonhomogeneous) or nonsignificant.

Skeleton

Lönnberg (1934) described *S. graffmani* from a specimen consisting of a "skin with the fins in situ, the upper jaw with the tooth row complete on the right side, and the complete lower jaw." The description included measurements of the upper and lower jaws and tooth counts. He later (1938) published a detailed description of the complete skeleton of a second specimen and tooth counts of a third. Hall and Kelson (1959) stated that the rostrum of *S. graffmani* is less than twice the length of the cranial portion of the skull and the tooth count is 43-47 in each row. Van Gelder (1960) published measurements and tooth counts for two skulls that he referred to *S. graffmani.* These four accounts make up the entire osteological literature for spotted porpoise from the eastern tropical Pacific.

The purpose of this section is to describe in qualitative and quantitative terms the development, sexual dimorphism, individual variation, and geographical variation of the skeleton.

Development

If skeletal measurements are to be used as taxonomic characters, we must know how each measurement changes during development. Here I describe patterns of change with development in the skull and postcranial skeleton. The account is based primarily on specimens collected in the tuna fishery aboard the M/V *Carol Virginia* in 1968 and M/V *Pacific Queen* in 1969. Sixty-four of the 69 specimens are divided into the following categories for the purposes of qualitative description:

Class I.	Near-full-term fetuses, with no dentinal layers: 4 (CB length 221 to 237 mm).
Class II.	Newborn individuals, with no dentinal layers: 5 (CB length 221 to 242 mm).
Class III.	Calves in the "two-tone" coloration phase described by Perrin (1970*a*), with 2-4 dentinal layers: 12 (CB length 331 to 236 mm).
Class IV.	Sexually immature subadults; coloration categories mostly "speckled" and "mottled" with some "fused," 4.5-8 dentinal layers: 23 (CB length 356 to 411 mm).
Class V.	Sexually mature but physically immature adults, with vertebral epiphyses not fused along full length of vetebral column and in coloration category "fused"; with 7-9.5 dentinal layers: 5 (CB length 369 to 406 mm).
Class VI.	Physically mature adults with all vetebral epiphyses fused; with 8 or more dentinal layers: 15 (CB length 360 to 404 mm).

The remaining seven specimens consist of: (a) the skulls only of five sexually mature animals, the degree of physical maturity of which is unknown, and (b) of two other specimens (LACM no. 27420, skull only, and LACM no. 27431, complete skeleton), from off Mexico and from an unknown locality in the tuna fishery, respectively, whose skeletal development falls between classes II and III, and are designated below as comprising Class II.5 (with one postnatal dentinal layer).

Cranial Skeleton

The usual practice in analysis of skull growth patterns is to express measurements not only absolutely but also as percentages of a given dimension of the skull. It has been traditional to express measurements as percentages of condylobasal length, but as several functional components of the skull are encompassed in this measurement, its pattern of increase (fig. 12) must of necessity be in itself very complex. Fraser and Noble (1968) initiated the use of parietal width as a comparative base and achieved, to them, more satisfactory results than by use of condylobasal length. In this account of developmental variation, however, the emphasis is on analysis of absolute growth of functional units, rather than on analysis of ratios or relative measurements.

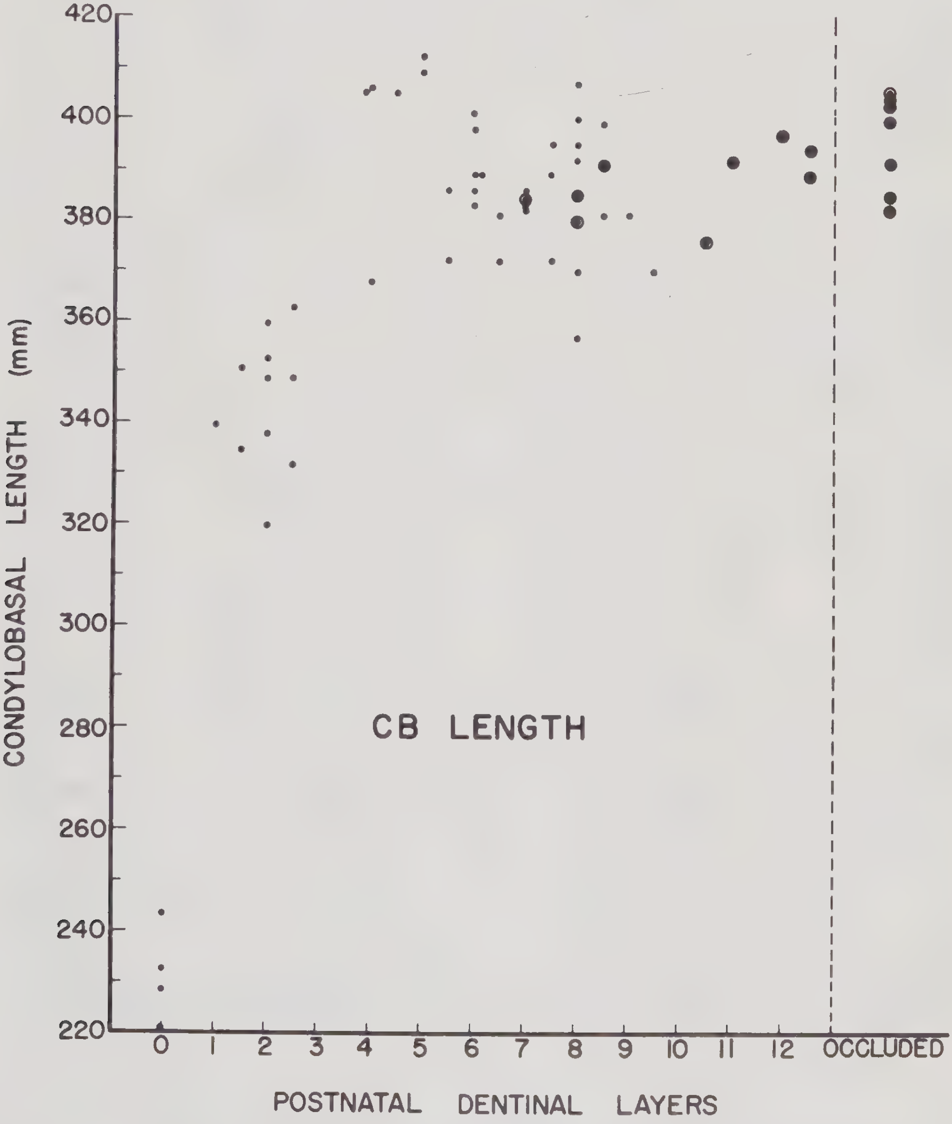


Figure 12. Development of skull of spotted porpoise: scatterplot of condylobasal length on number of postnatal dentinal layers. Large blackened symbols represent fully physically mature specimens, circled symbols represent specimens of unknown degree of physical maturity.

The delphinid skull can be divided into several functional components; namely, the braincase, the feeding apparatus, the vision apparatus, the hearing apparatus, and the breathing and sound-producing apparatus. A priori, it seems obvious that each component would have its own, to a certain extent independent, pattern of development and a typical variance. For example, a young porpoise must breathe immediately upon birth, but need not catch prey until it is weaned, therefore it is to be expected that development of the breathing apparatus will be faster than that of the feeding apparatus. Sound is very important to cetaceans, and sound quality is closely tied to structure. Therefore, it is to be expected that the hearing apparatus will show relatively low plasticity.

The respective developmental patterns should be to a lesser or greater degree correlated, because (1) the direction of development is the same for all, that is, positive, and (2) the systems are physically contiguous and often share ossifications. For example, the posttemporal fossa, as the origin of the temporal muscle, is part of the feeding apparatus, but its dimensions also vary with the braincase, as it is part of the lateral wall of the cranium. Similarly, the mandibular fossa is part of the hearing apparatus, but its length must to some extent be influenced by that of the ramus, which is part of the feeding apparatus. Covariation notwithstanding, however, it makes sense to consider development of the skull in terms of the various functional systems, and that scheme is adhered to in the following account.

Braincase. The degree of ossification of the elements of the braincase (fig. 13) at birth (Classes I and II described above) varies greatly. Posteriorly, ossification may be essentially complete or large fontanelles may persist at the confluence of the parietal, exoccipital and supraoccipital.

By the time one postnatal dentinal layer has been laid down in the teeth (Class II.5) the fontanelles are completely closed. The floor of the braincase is formed medially by the basoccipital, the basisphenoid, and the presphenoid. Ventrolaterally, the alisphenoids extend from the basisphenoid to meet the squamosals, parietals, and frontals, dividing the large ventral hiatus into two parts. The partition of the hiatus by the orbitospenoid may not be complete at birth. During early postnatal development the orbitosphenoid expands anteriorly to close completely the forward portion of the hiatus, and posteriorly to reduce the posterior portion, which persists into adulthood to varying degree as the optic foramen. Dorsolaterally, considerable variation is exhibited at birth in the shapes of the frontal, supraoccipital, and parietal bones. Miller (1923) described the telescoping process that culminates in formation of the supraoccipital crest. During telescoping, the interparietal becomes decreasingly visible in dorsal view of the skull and the suture between the interparietal and supraoccipital rapidly becomes obliterated medially. Lateral traces of the suture persist, however, in specimens of Class III.

The lower part of the parietobasoccipital suture becomes incorporated into the posterior margin of the supratemporal fossa. The progress of closure of the remainder of the parietooccipital sutural system varies greatly. In most adult specimens (Classes V and VI) it is obliterated, but traces remain even in some specimens of Class VI; so degree of closure may not by itself be used as a criterion of age.

The remaining visible sutures of the braincase, the squamosal (within the supratemporal fossa), the alisphenoidal, and the orbitosphenoidal, show signs of fusion only in some of the oldest individuals (Class VI).

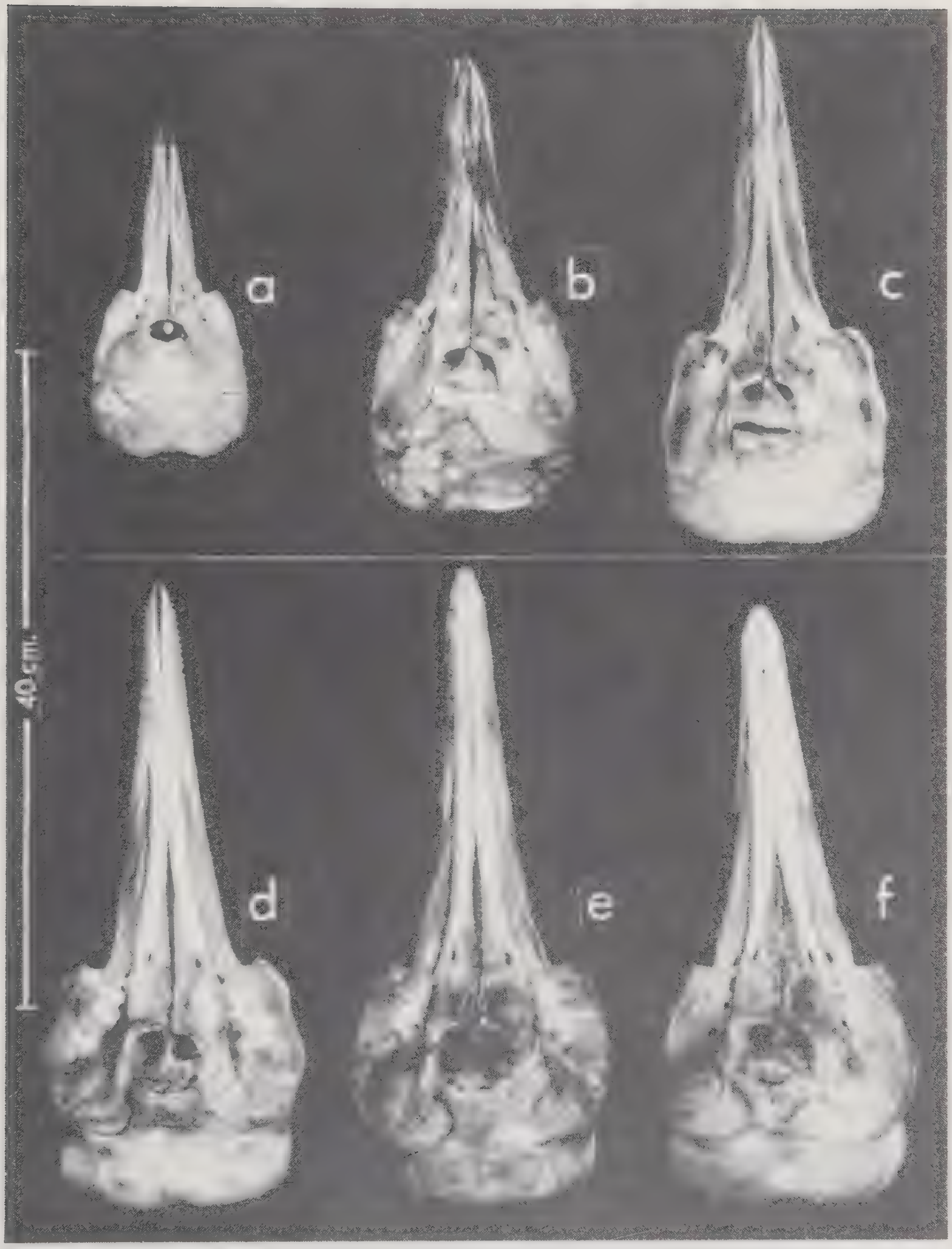


Figure 13. Dorsal view of crania in a developmental series of skulls of spotted porpoise: (a) USNM no. 395461, female, no postnatal dentinal layers, Class II; (b) LACM no. 27431, sex unknown, one layer, Class II.5; (c) USNM no. 395610, female, 2 layers, Class III; (d) USNM no. 395397, sexually immature female, 4.5 layers, Class IV; (e) USNM no. 395598, sexually mature but physically immature male, 8 layers, Class V; (f) USNM no. 395597, sexually and physically mature male, 12.5 layers, Class VI.

The foramen magnum is pyriform at birth and becomes oval to varying degree during subsequent development. With some individuals of Class VI the foramen magnum remains pyriform.

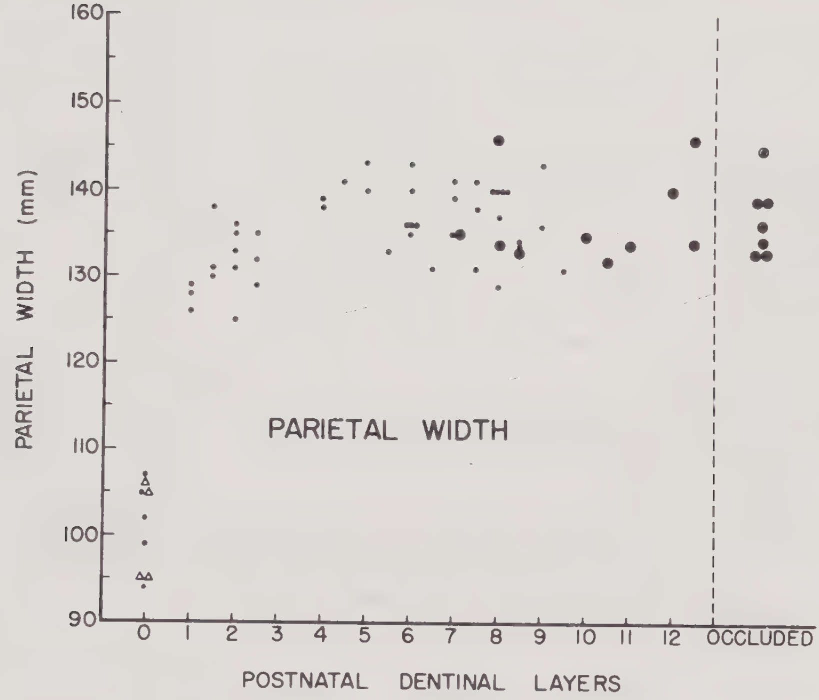
Small, apparently nonfunctional foramina may pierce the occipital region posteriorly and ventrally. Although the foramina are large and more numerous among specimens of Classes I, II, and III than in older specimens, they also occur in some physically mature specimens (Class VI).

Scatterplots of the measurements of parietal width and height, and length of the braincase on the number of postnatal layers in the tooth dentine (figs. 14 and 15) show that near-maximum dimensions are attained early in development, long before the onset of sexual maturity (at 4-6 layers) after an initial period of very rapid growth. All dimensions of the braincase appear to continue to increase slowly after the initial rapid growth phase. Regression analysis shows increase in height to be most correlated with age in this phase ($r = .339$, $.02 > P > .01$). An index (fig. 15) compounded of the three measurements [width + height + length ÷ 3] allows easier assessment of this gradual increase by damping the effect of individual variation in proportions and also, being directly proportional to the cube root of cranial volume measured externally, serves as an index of cranial volume. The total increase in the average dimension over the period of gradual growth is approximately 8 mm. To test the possibility that this increase might result from thickening of the cranial wall rather than an actual increase in cranial volume, I drilled a hole in the parietal area of each of four skulls and measured the thickness of the cranial wall. This yielded an expected increase in 1.8 mm in parietal width owing to increasing thickness of the cranial wall. This is much less than the actual average increase of about 8 mm (fig. 15); it must be assumed that the internal cranial dimensions and therefore cranial volume continue to increase after the initial rapid-growth phase. If the cranium be assumed to approximate a sphere, the increase in volume over the period covered by the increase from 2 layers to 13 layers can be roughly estimated as $1/6\ \pi\ [118.2)^3 - (112)^3]\ \text{mm}^3$ (using the approximate mean values of the volume index in fig. 15 and deducting the growth owing to increased thickness of the cranial wall), or $129\ \text{cm}^3$.

Feeding Apparatus. The parts of the skull concerned primarily with feeding are the rostrum, the posttemporal fossae, the zygomatic and postorbital processes (which bound the posttemporal fossa anteriorly and determine its depth), the mandible, the teeth, and the hyals.

The rostrum is fully ossified at birth, and changes little during subsequent development in the relations and proportions of its various elements, despite the great increase in size (figs. 13-16). In lateral aspect, as the maxillaries grow down to enclose the alveoli, the premaxillaries proportionately become decreasingly elevated above the level of the maxillaries.

The onset of distal fusion of the premaxillaries and maxillaries is variable. Some sexually immature animals (Class IV) exhibit slight fusion and some individuals of Class V exhibit more. Fusion, however, usually occurs at about the onset of sexual maturity (in Class V). The tip of the rostrum begins to thicken laterally and dorsally, until in most old individuals it becomes blunt, quite unlike the rostrum of most younger adults. The mandible follows a similar course of development, with symphyseal fusion commencing in Class V and the tip becoming blunt in older animals.



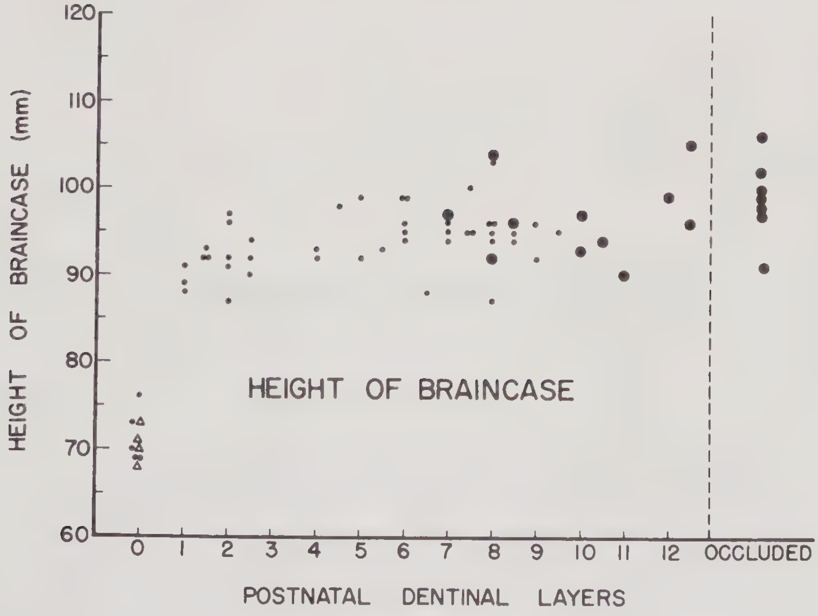


Figure 14. Development of skull of spotted porpoise: scatterplots of parietal width (top) and height of braincase (bottom) on number of postnatal dentinal layers. Triangles are fetuses. Small dots are physically immature specimens. Large dots are physically mature specimens. Circled dots are specimens of unknown degree of maturity.

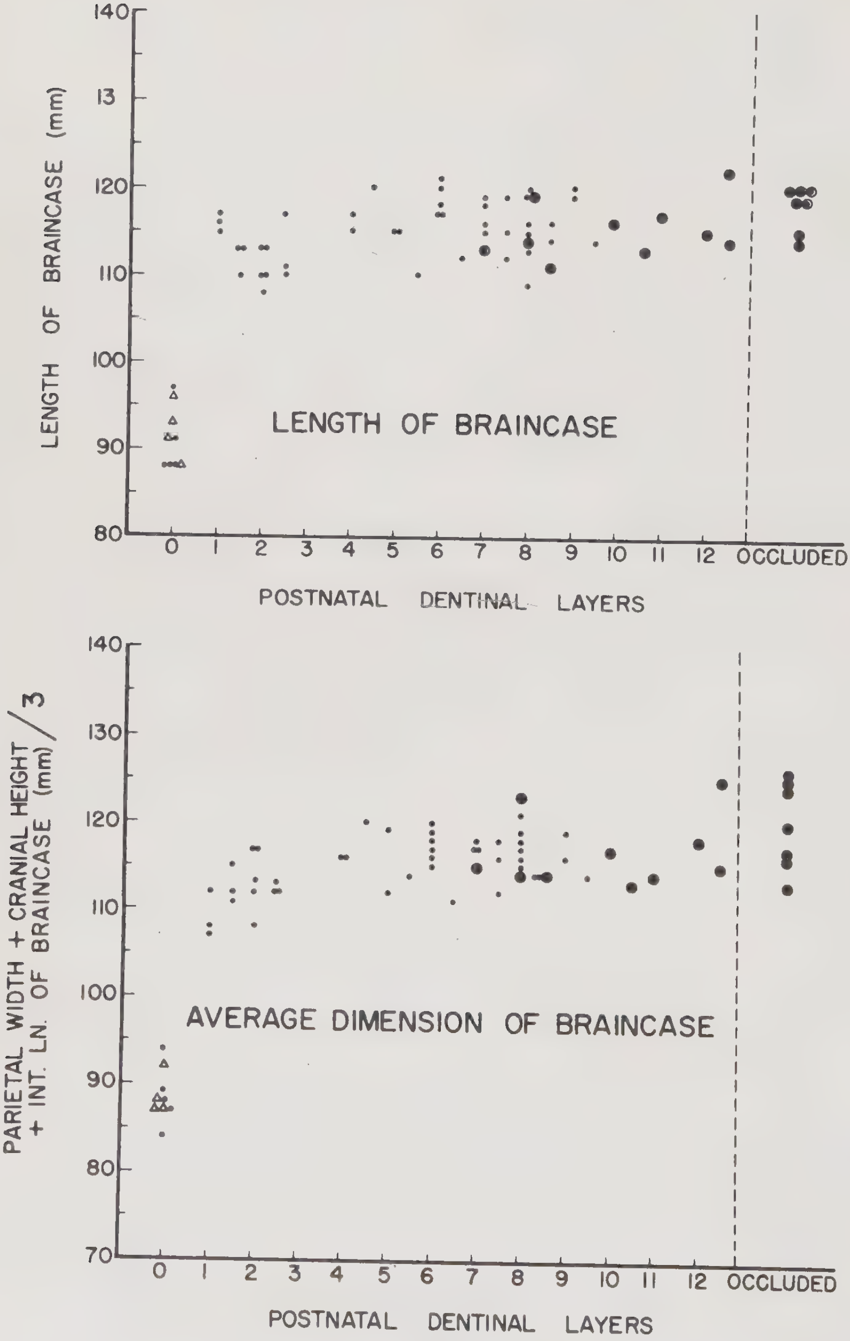


Figure 15. Development of skull of spotted porpoise: scatterplots of length of braincase (top) and average dimension of braincase (bottom) on number of postnatal dentinal layers. Symbols same as figure 14.

The measurements reflecting length of the beak (namely, length of rostrum [fig. 16], length of upper tooth row, length of mandibular ramus, and length of lower tooth row) all increase in a similar manner, with very rapid growth during Classes I to III ($\leqslant$4 dentinal layers) and attainment of an adult plateau of beak length in Class IV ($>$4 layers). Older animals vary less in beak length, but this may be owing to sampling error, as the younger classes are represented by larger samples. The projection of the premaxillaries beyond the maxillaries likewise shows no change after attainment of the adult plateau.

Ratio of rostrum length to basal width, cranial length, and condylobasal length have been used in the taxonomy of *Stenella* (Gray, 1846; Hall and Kelson, 1959; Van Gelder, 1960; Fraser, 1950), and, while the emphasis in this account is on absolute growth of functional units, plots of these ratios on number of dentinal layers (fig. 16) are presented to provide bases of comparison with previous taxonomic work. The respective variances of these measures is discussed below in the section on individual variation. Of the three, the ratio of rostrum length to basal width appears to show least correlation to age.

Although the length of the rostrum reaches a plateau relatively early in development, it continues to grow in width anteriorly (fig. 17) well into adulthood, primarily owing to anterior broadening of the premaxillae.

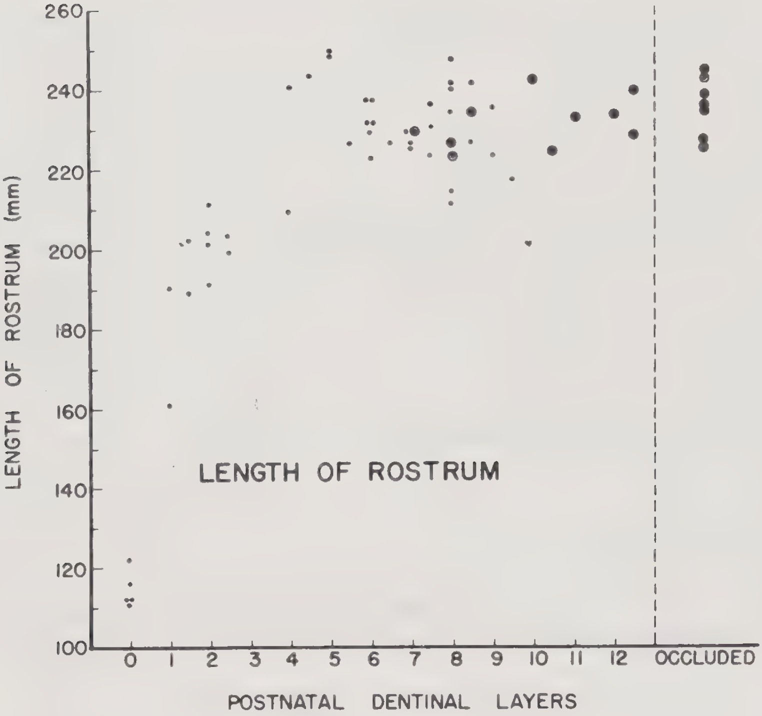
Comparison of the slopes of linear regressions of log width at base, midlength, and 3/4 length of the rostrum on log of dentine layers (table 8) shows that the growth rate for width is greatest in the distal portion of the rostrum, decreasing proximally.

Table 8. Results of log-log regression analyses of rostral widths on number of postnatal dentinal layers.

Measurement	Sample	Log Equation Intercept a Slope b[1]	Correlation coefficient r
Width of rostrum at base	52	Y = 1.874 mm + .105 X	.963
Width at 1/2 length	60	Y = 1.587 mm + .127 X	.874
Width at 3/4 length	57	Y = 1.414 mm + .143 X	.835

[1] Growth coefficient α in arithmetic growth equation $Y = a + bX^{\alpha}$

The postorbital process, zygomatic process (excluding its mesoventral projection), and (supra- or post-) temporal fossa are components of the feeding apparatus, because they are functionally tied to the temporal muscle. The two processes enclose the temporal fossa, through which the temporal muscle passes. The "posttemporal" fossa is the area occupied by the origin of the muscle, delineated by the posterior perimeter of the temporal fossa proper. In addition, the zygomatic process of the squamosal also functions as the pivot for the lower jaw.



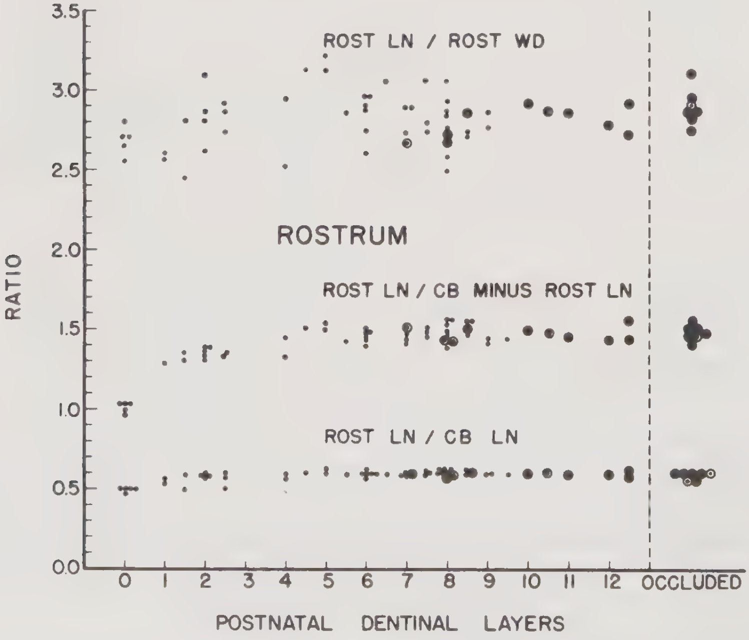


Figure 16. Development of skull of spotted porpoise: scatterplots of length of rostrum (top) and proportional rostral measurements (bottom) on number of postnatal dentinal layers. Symbols same as figure 14.

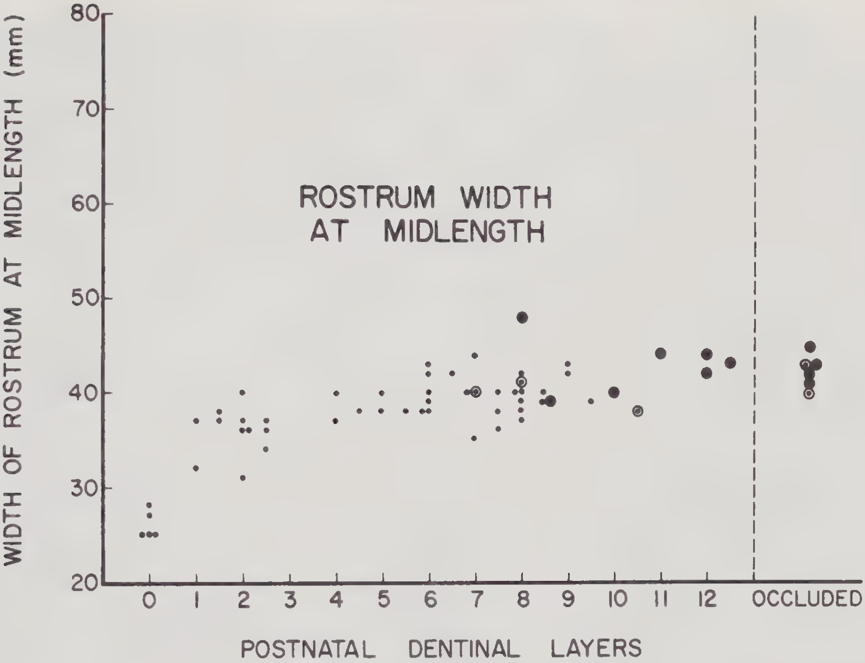


Figure 17. Development of skull of spotted porpoise: scatterplot of rostrum width at midlength on number of postnatal dentinal layers. Symbols same as figure 14.

The postorbital process becomes proportionately more massive with development and projects at an increasingly greater angle from the cranium. At the same time the temporal fossa enlarges and changes in cross section from a flattened oval to a subtriangular or pyriform oval (fig. 18). The zygomatic process shows a similar pattern of development in massiveness and angle of projection.

The posterior limits of the posttemporal fossa are vaguely suggested in Class I and II skulls by bone texture and contour, but it is not until Class III that the fossa is clearly delineated. In older animals, the hindmost rim of the fossa, formed at the parietoexoccipital suture, becomes increasingly thickened and rugose. The squamous portion of the squamosal invades the fossa area, overlaying the parietal, until it reaches its maximum development in Class IV skulls.

The teeth are an important part of the feeding apparatus. At birth they are set in long slots, with very slight ridges delineating the positions of future alveoli. The maxillary furrow for its full length completely penetrates to the underlying premaxillary bone. In the mandible, the furrow penetrates to the mandibular fossa. In Class III skulls the furrows are floored, and in Class IV skulls the alveoli are partitioned off.

The basihyal, thyrohyals, and stylohyals (fig. 19) act as anchors for important muscles involved in lowering the jaw, moving the tongue, and swallowing (Lawrence and Schevill, 1965). Therefore, although these hyoid bones certainly are involved in other functional units, the description of their development is included here in the account of the feeding apparatus. The stylohyals are included below in consideration of the breathing and sound-producing apparatus.

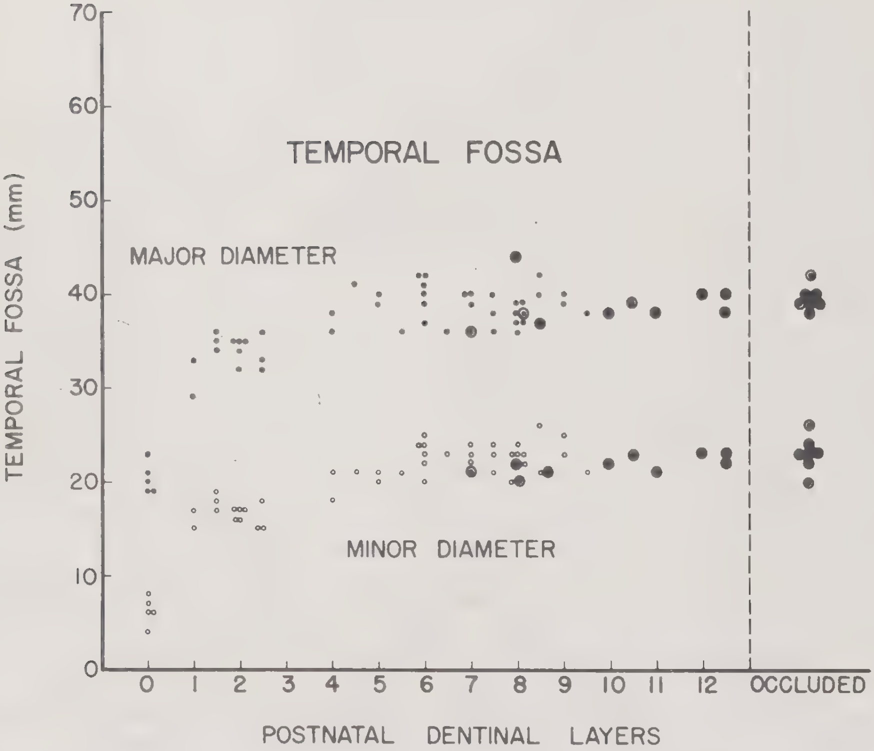


Figure 18. Development of postemporal fossa of spotted porpoise: scatterplot of diameters of postemporal fossa on number of dentinal layers.

At birth, the thyrohyals are not fused to the basihyal, and considerable variation is exhibited in shape of the thyrohyals. Complete fusion of the thyrohyals and basihyal occurs quite late in development (figs. 19 and 20), and does not appear to be correlated with the attainment of physical maturity as adjudged by fusion of the vertebral epiphyses. Some individuals with unfused epiphyses have completely fused hyals, and vice versa.

The basihyal and thyrohyals grow like the other elements of the feeding apparatus, that is, they exhibit a protracted rapid growth phase followed by a flat plateau. An apparent continued growth in length of the osseous thyrohyal in adulthood results from delayed ossification of the proximal cartilaginous portion in fusion of the basihyal and thyrohyals.

Hearing Apparatus. The tympanoperiotic bones are indisputably part of the hearing apparatus. In addition, following Fraser and Purves (1960), I consider the portion of the underside of the skull posterior to the base of the rostrum and lateral to the bony nares and basicranial trough, excluding the zygomatic arch, the glenoid fossa of the squamosal, and the orbital processes, to be functional in hearing. The excavations and sculpturing in this region reflect the positions of air-filled sinuses that presumably insulate the animal's inner ear from phonations produced somewhere in the nasopharyngeal system.

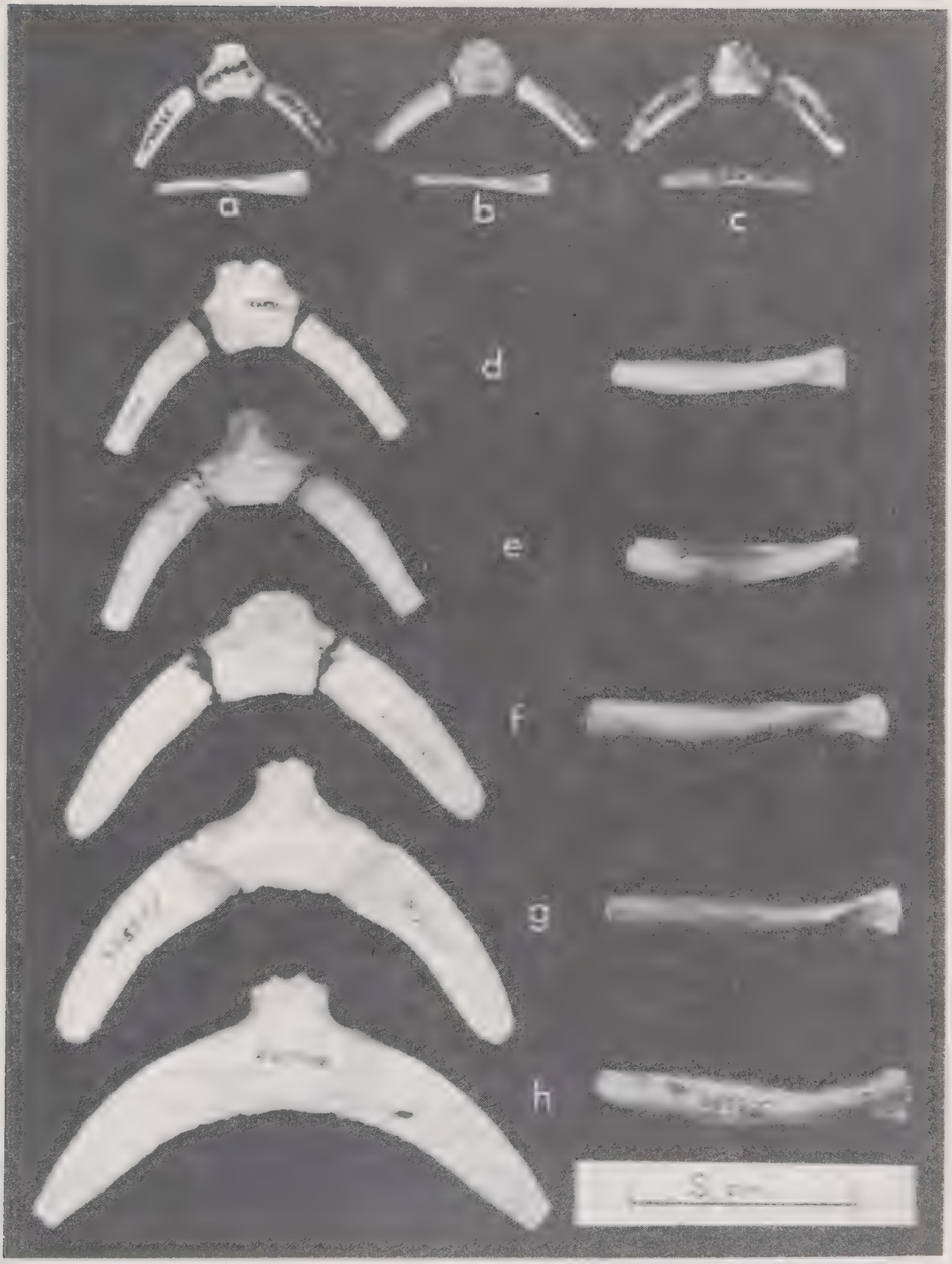


Figure 19. Hyal bones of spotted porpoise: (a-c) neonatals, Class II; (d) Class II.5; (e) Class III; (f) Class IV; (g) Class V; (h) Class VI.

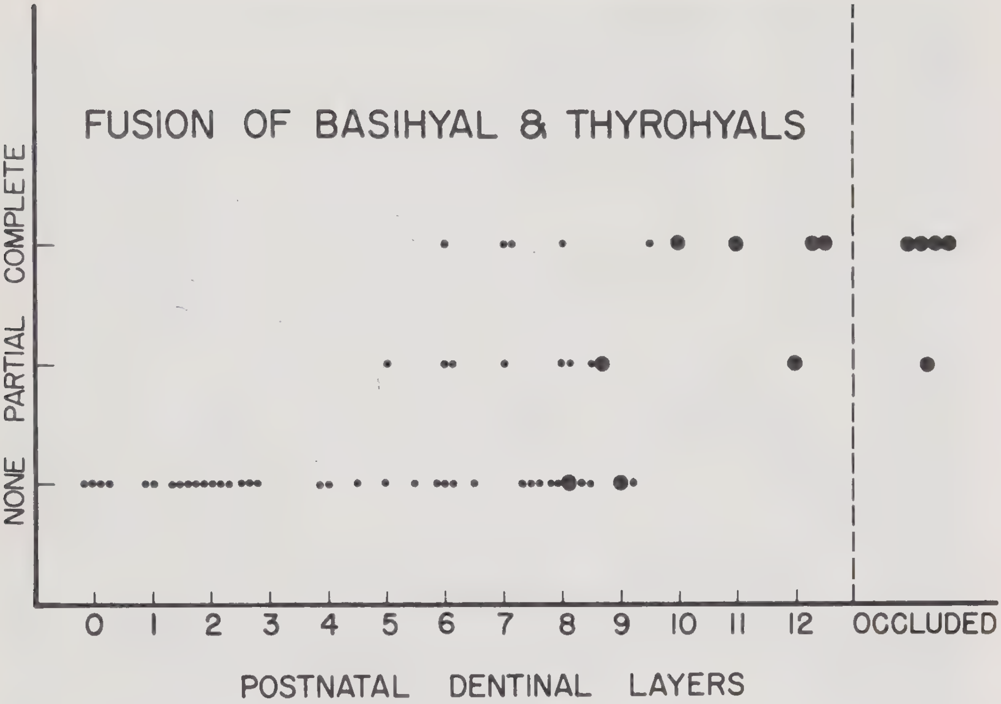


Figure 20. Development of hyoid bones of spotted porpoise: scatterplot of degree of fusion on number of dentinal layers. Symbols same as figure 14.

Following Norris (1963), I provisionally assume that certain elements of the mandible are involved in hearing and therefore also include in the "hearing apparatus" the mandibular fossa and the very thin angular process. The angular process is strongly developed uniquely in Cetacea and apparently does not function as a major muscle anchor. Its presumed function is to bring the end of the mandibular fossa and of its contained fat organ down and back to a position nearly adjacent to the tympanoperiotic, providing a lateral "acoustic window."

In addition to the internally situated incus, malleus, and stapes, the tympanoperiotic has three major components: the periotic, the tympanic bearing the bulla, and the mastoid process. The periotic, including the portion housing the cochlea, is nearly fully developed at birth and shows an average change in length during development of only about 1 mm (fig. 21). The bulla lengthens rapidly after birth about 2 mm to reach the adult plateau of development in Class II.5 animals (1 tooth layer). The mastoid process is similarly fully developed in Class II.5 individuals.

Development of the falciform process of the squamosal parallels closely that of the tympanoperiotic complex, reaching completion in Class II.5 animals.

The air sinus system around the tympanoperiotic, or at least the vestiges of it as seen in the skull, reaches approximately adult configuration in Class II.5 animals, with thickness of isolating spaces greatly increased over that at birth. The supratympanoperiotic hiatus begins to be diminished after birth by osteosclerotic extensions of the squamosal, occipital, and alispenoid, and in most Class III skulls the foramen ovale is partitioned off

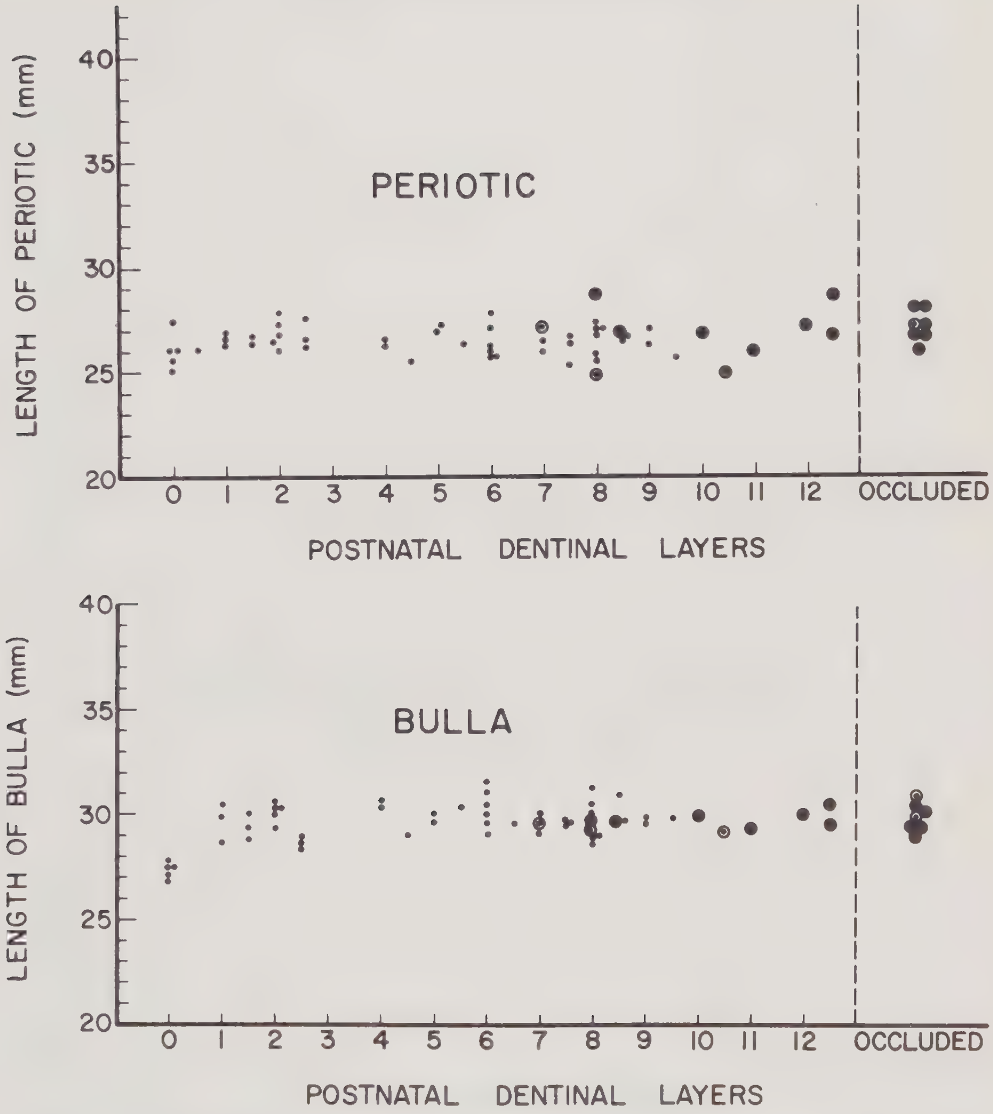


Figure 21. Development of skull of spotted porpoise: scatterplot of length of periotic (top) and bulla (bottom) on number of dentinal layers. Symbols same as figure 14.

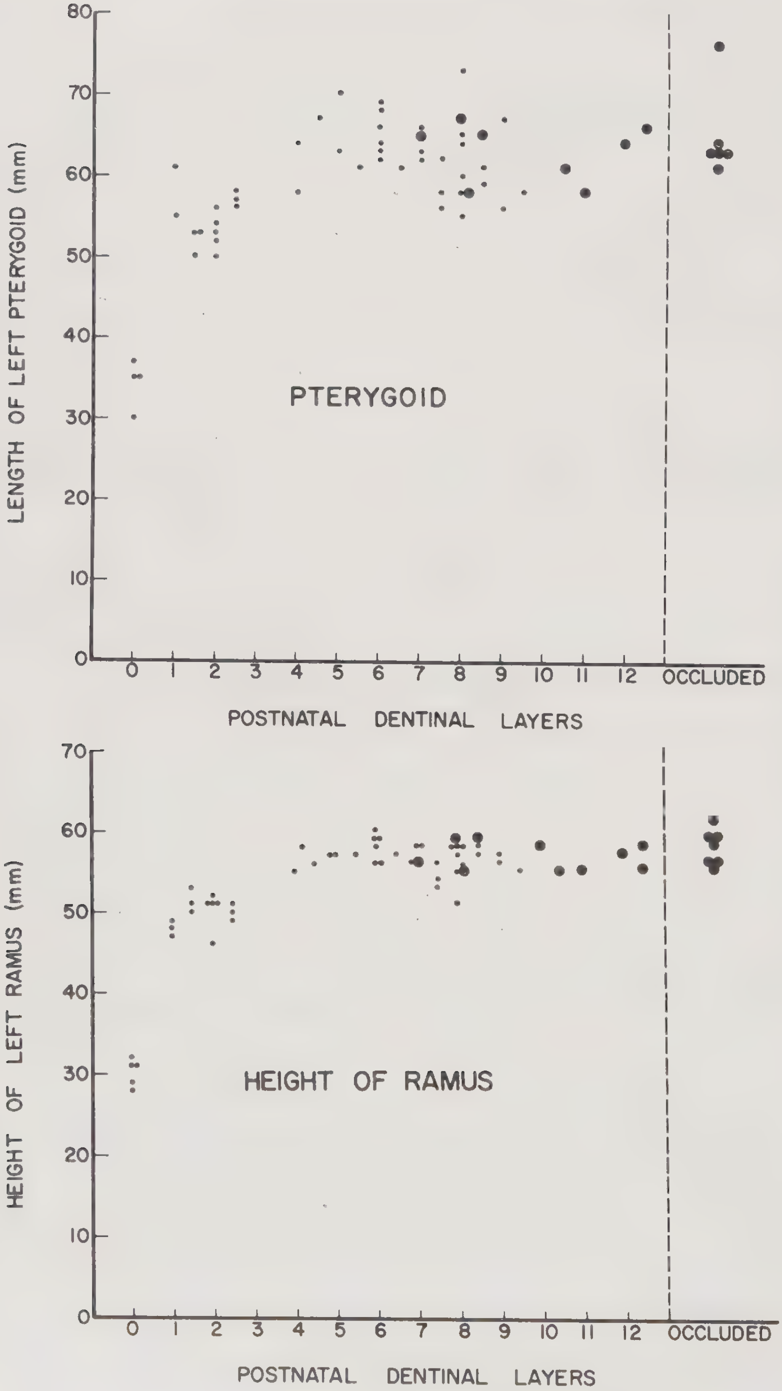


Figure 22. Development of skull of spotted porpoise: scatterplots of length of pterygoid (top) and height of mandibular ramus (bottom) on number of dentinal layers. Symbols same as figure 14.

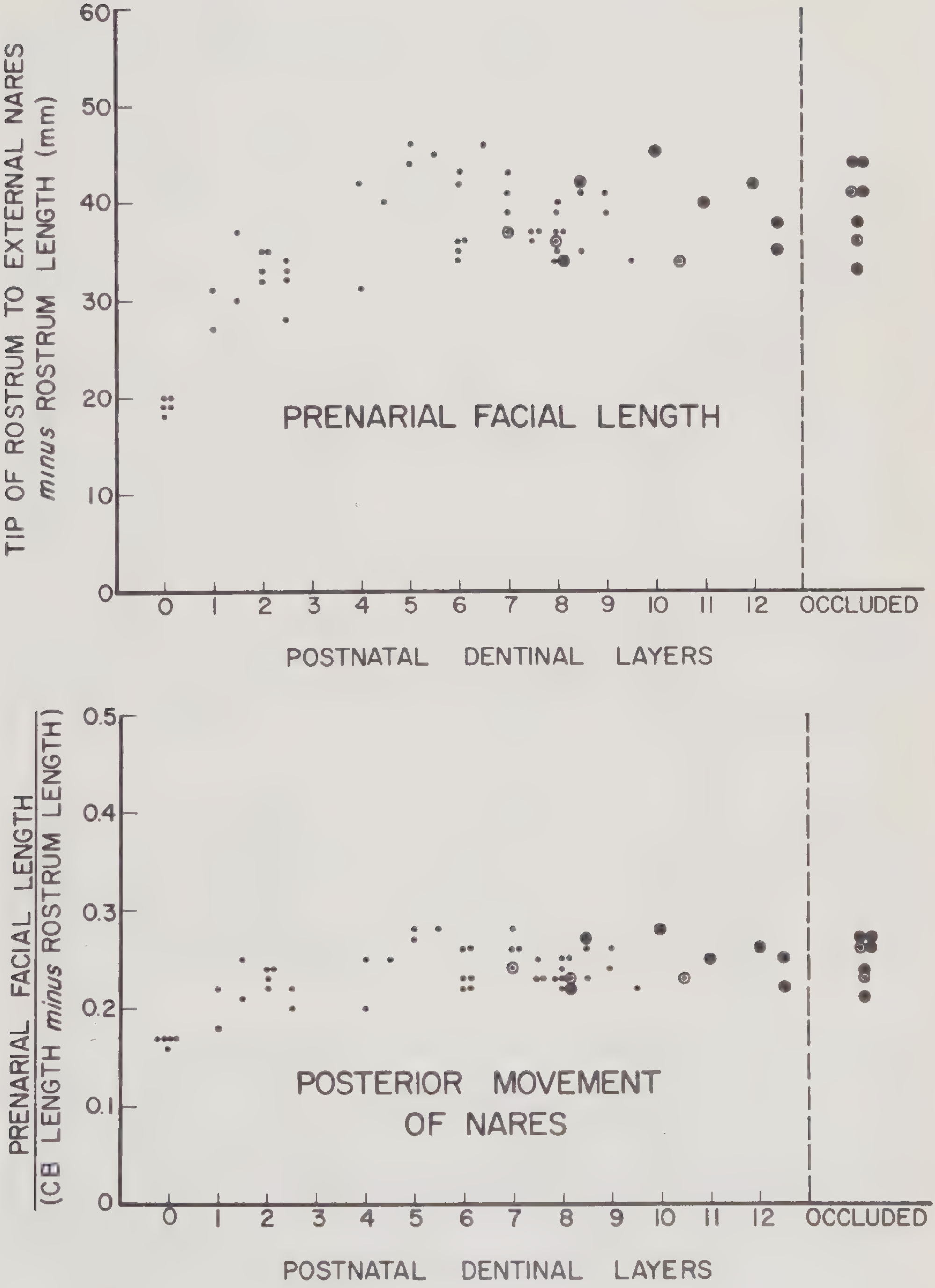


Figure 23. Development of skull of spotted porpoise: scatterplots of prenarial facial length (top) and posterior movement of nares (bottom) on number of dentinal layers. Symbols same as figure 14.

from the hiatus. The subsequent course of reduction of the hiatus, however, varies greatly; some old animals possess quite large openings. The anterior portions of the air sinus system, including the pterygoid fossae, also reach essentially the adult state in Class II.5 skulls. The exception is development of the pterygoid hamuli. Variation in the standard measurement Tip of rostrum to mesial end of posterior edge of left pterygoid, which reflects development of the pterygoid, obviously must be influenced greatly by variation in length of the contained rostrum. A better measure of pterygoid development is Greatest length of the pterygoid (fig. 22). This measurement, exhibiting a protracted initial rapid growth phase, is similar to that of the feeding apparatus. This is interesting in light of Lawrence and Schevill's (1965) suggestion that the pterygoid hamuli may function in feeding to extend the hard palate and direct food away from the end of the larynx.

The measurement of height of the madibular ramus (fig. 22) shows a pattern of increase intermediate between that of the tympanoperiotic and that of dimensions most directly reflecting development of feeding ability, that is, the cross-sectional area of the temporal fossa (fig. 18) with the flat adult plateau attained in young Class IV skulls. This intermediacy is to be expected, because the measurement encompasses the coronoid portion of the ramus, which functions as the area of insertion of the temporal muscle, and the angular process, which probably functions in hearing. The length of the mandibular fossa increases similarly but is influenced by the length of the lower jaw.

Vision apparatus. The antorbital process and supraorbital shelf must certainly function in protecting the eye. The measurements across these structures, however, incorporate the breadth of the facial region. The facial region is primarily functional in breathing and/or sound production (see next section). The length of the orbit stabilizes in Class IV skulls at the adult level.

Breathing and sound-producing apparatus. The most significant feature of the odontocete skull which has to do with breathing is its telescoping (described in detail by Miller, 1923). Telescoping brings the bony nares from the end of the rostrum to a proximal, dorsal position, an adaption to allow the animal to breathe rapidly without lifting his head high out of the water. The expansion of the supraorbital wings of the maxillaries and frontals, also described by Miller, and the occipital crest, provide areas of attachment for muscles functional in breathing (Lawrence and Schevill, 1956). These muscles, and the "basining" (Miller, 1923) of premaxillaries, nasals, and mesethmoid, may also function in sound production and transmission (Norris, et al., 1961; Evans and Prescott, 1962).

Telescoping, or posterior movement of the nares and the adjacent maxillaries, is well along at birth and essentially complete in Class II skulls (fig. 13). The measurement Tip of rostrum to mesial end of anterior transverse margin of right nares reflects position of the nares, but includes the rostrum. A better measure of postnatal development is provided by subtraction of rostral length. This distance reaches adult level in Class IV skulls (fig. 23). The postnatal progress of telescoping, or posterior movement of the nares, can be followed by examining the change in the ratio between this measurement and condylobasal length minus rostrum length (fig. 23).

The pattern of development of this region and of the widths of the external and internal nares is like those of elements of the hearing apparatus, with a short initial rapid growth phase and early attainment of a flat adult plateau in Class IV skulls.

The areas of muscle attachment on the maxillaries, frontals, dorsal and posterior faces of the nasals, and in the prenarial triangle (the origin of the blowhole plug muscle) become increasingly rough and rugose with age. With the exception of the region bordering the antorbital notch, these areas are all smooth at birth. Class IV skulls are extensively roughened, and Class VI skulls are most rugose. The area of insertion of the antero-external layer of the maxillonasolabial muscle (see Lawrence and Schevill, 1956) becomes increasingly thickened and rugose with age, resulting in thickening of the antorbital process.

The extremely variable supraoccipital crest reaches maximum development as measured by occipital overhang in specimens of Class IV and V, and exhibits some erosion in specimens of Class VI (fig. 24). In physically mature individuals (Class VI) the accessory occipital rugosities vary in degree of development.

The measurement of the distance from the anterior end of the junction between the nasals to the hindmost point of the supraoccipital crest is influenced by two forces during development (fig. 24). As telescoping proceeds in early development, with the frontals and associated nasals slipping over the interparietal, the distance decreases sharply. In later development, as the supraoccipital crest thickens, the distance increases to level off to a plateau in physically mature specimens.

The premaxillary shield develops more slowly than the external nares; adult width is attained at Class IV. The postnarial shield, composed of the mesethmoid and anterior surfaces of the nasals, reaches near-adult development much earlier. Anteriorly, a large gap exists at birth between the frontals. A projection of the mesethmoid extends upward into the gap. At or near birth, two accessory centers of ossification appear, and by the time two layers have been laid down in the teeth (Class III), the mesethmoid has reached its adult state of development, overlapping the frontals and nasals to varying degree. The asymmetry of the narial region of the delphinid skull may be linked functionally to sound production. Asymmetry is nearly fully developed at birth and does not decrease during subsequent development as it does in *Psuedorca* (Yamada, 1956).

The pattern of growth of the stylohyal is like that of the prenarial facial length (fig. 23).

Summary. The functional units of the skull have different patterns of postnatal development (fig. 25). At birth, the hearing apparatus and some elements of the breathing and sound-producing apparatus (asymmetry and the postnarial shield) are most precocious, followed by the vission apparatus, the braincase, other elements of breathing and sound-producing apparatus, and the feeding apparatus, in that order. All but the braincase and one component of the breathing and sound-producing system (the internal nares) reach adult size in some Class IV specimens (2-4 dentine layers). The braincase and width of the internal nares continue to grow into physical maturity. The rates of

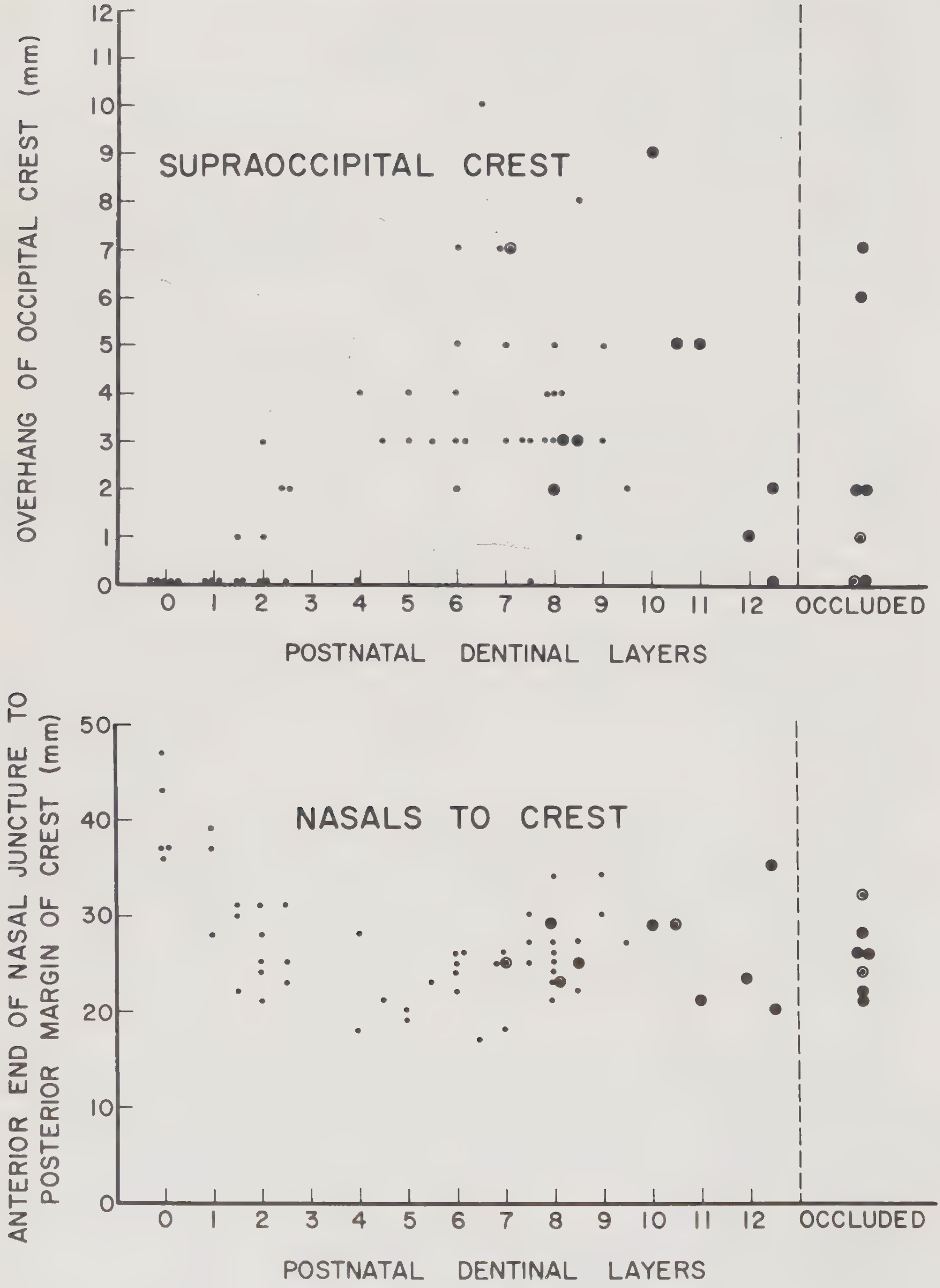


Figure 24. Development of skull of spotted porpoise: scatterplots of overhang of supraoccipital crest (top) and nasals-to-crest distance (bottom) on number of dentinal layers. Symbols same as figure 14.

growth of the other four units are inversely proportional to the respective degrees of precocity at birth, the feeding apparatus growing most rapidly and the nearly fully developed hearing apparatus most slowly. Some standard measurements that pertain to more than one functional unit show intermediate patterns of increase, and others, such as distal width of the rostrum, may be influenced by secondary sexual dimorphism and are therefore more properly considered in that context.

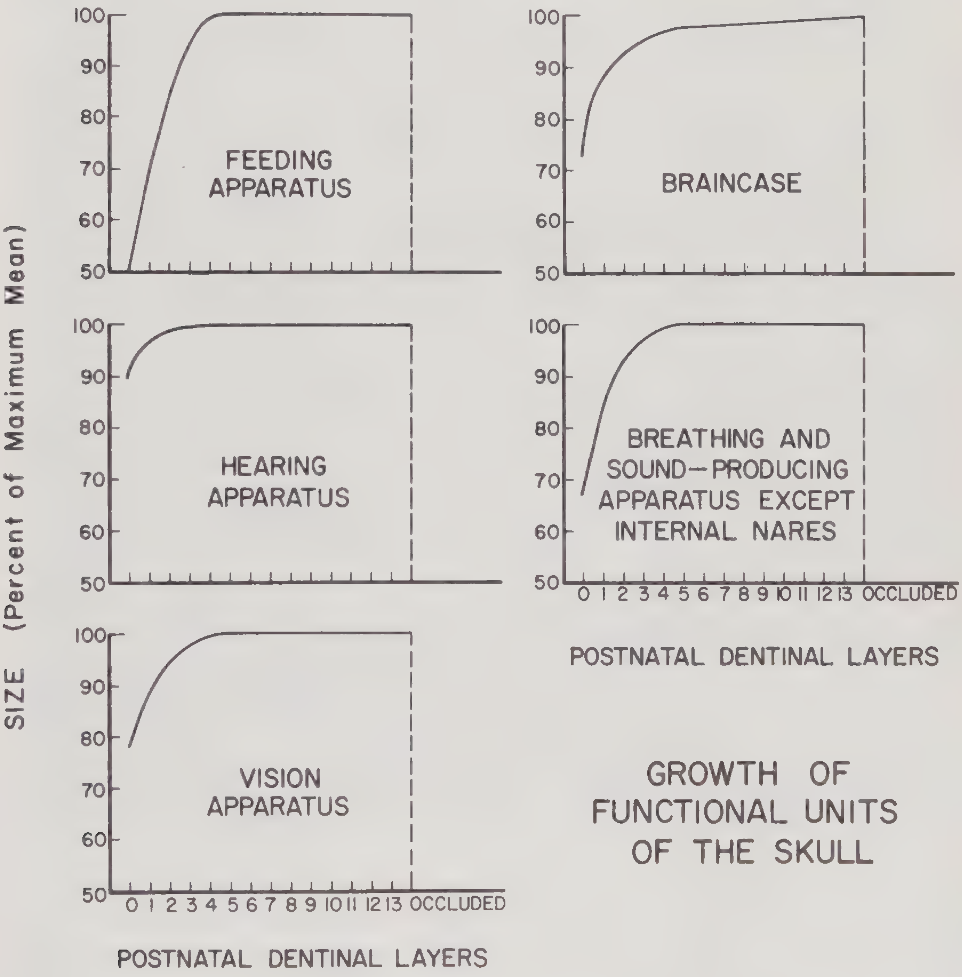


Figure 25. Comparative growth of functional units of the skull of the spotted porpoise, based on average growth rates.

Postcranial skeleton

Variation with growth is analyzed for the axial, anterior appendicular, and posterior appendicular elements of the postcranial skeleton.

Axial postcranial skeleton (fig. 26). At birth, none of the veterbral centra are fused. The neural arches of the atlas and axis are partially fused in some individuals. The neural arches are not yet ankylosed to the centra, and the halves of the neural arches of the first 10-15 vertebrae are not yet ankylosed dorsally. Ossified transverse processes are not yet developed on any vertebrae. In Class II.5 skeletons, the centra and neural arches of the atlas and axis are partially fused, all neural arches are complete and ankylosed to the centra, and ossified transverse processes are present on the atlas, axis, and postcervical vertebrae. The neural arches of 1-3 cervicals may remain permanently incomplete. Fusion of the atlas and axis is not complete until Class IV or V. Class VI specimens may exhibit fusion of the neural arches of the first three cervicals and fusion of the arches and centra of the remaining cervicals in varying combination. The atlas reaches adult dimensions in Class II.5 skulls in width of the articulating surface, in length of transverse process (fig. 27), and in height, which includes height of the articulating surface and height of the neural canal. The neural process (fig. 27) continues to lengthen into adulthood. The transverse processes of the axis develop in the same manner as those of the atlas. The neural spine of the atlas-axis complex may bifurcate with age or remain blunt. Anteriorly, the ridge of the neural spine is well developed in Class III. In Class III and older specimens a small dorsomesially projecting spine may arise at the dorsal end of each half of the articulating surface of the atlas.

The ventrolateral processes on the fifth, sixth, and seventh cervicals are absent at birth but develop to varying degrees to near the adult level in Class III. The tremendously variable first thoracic neural spine develops like the spine of the atlas-axis complex. The remaining neural spines continue to lengthen at least through Class V by distal ossification.

The rate of developmental increase (the value of Huxley's growth coefficient α) during the rapid growth phase of vertebral height decreases from the cephalic end of the vertebral column toward the middle of the column. This is evident in comparison of vertebral heights (centrum plus neural canal) of the atlas-axis complex, first thoracic, and first lumbar. In other words, the age increases at which mature size and proportions are attained. The same pattern is shown by vertebral width (fig. 27), a measurement including the centrum and the transverse processes. Judging from fusion of epiphyses and centra, the vertebrae in the lumbar region also continue to grow in length (fig. 27) until the onset of physical maturity. This protracted growth in the postcranial skeleton agrees with the results for external proportions, indicating cessation of cephalic growth at or before puberty, with continual growth of postcephalic body into adulthood (fig. 27).

The halves of the first 8-10 hemopophyses (chevron bones) are unankylosed at birth. In Class II.5 specimens, all hemopophyses are usually ankylosed, and the first 2-5 arches may be fused to each other in various combinations. In some cases, portions of the first few arches may remain discrete. The hemopophyses continue to lengthen through elongation of the ventral keel at least until physical maturity is reached in Class VI.

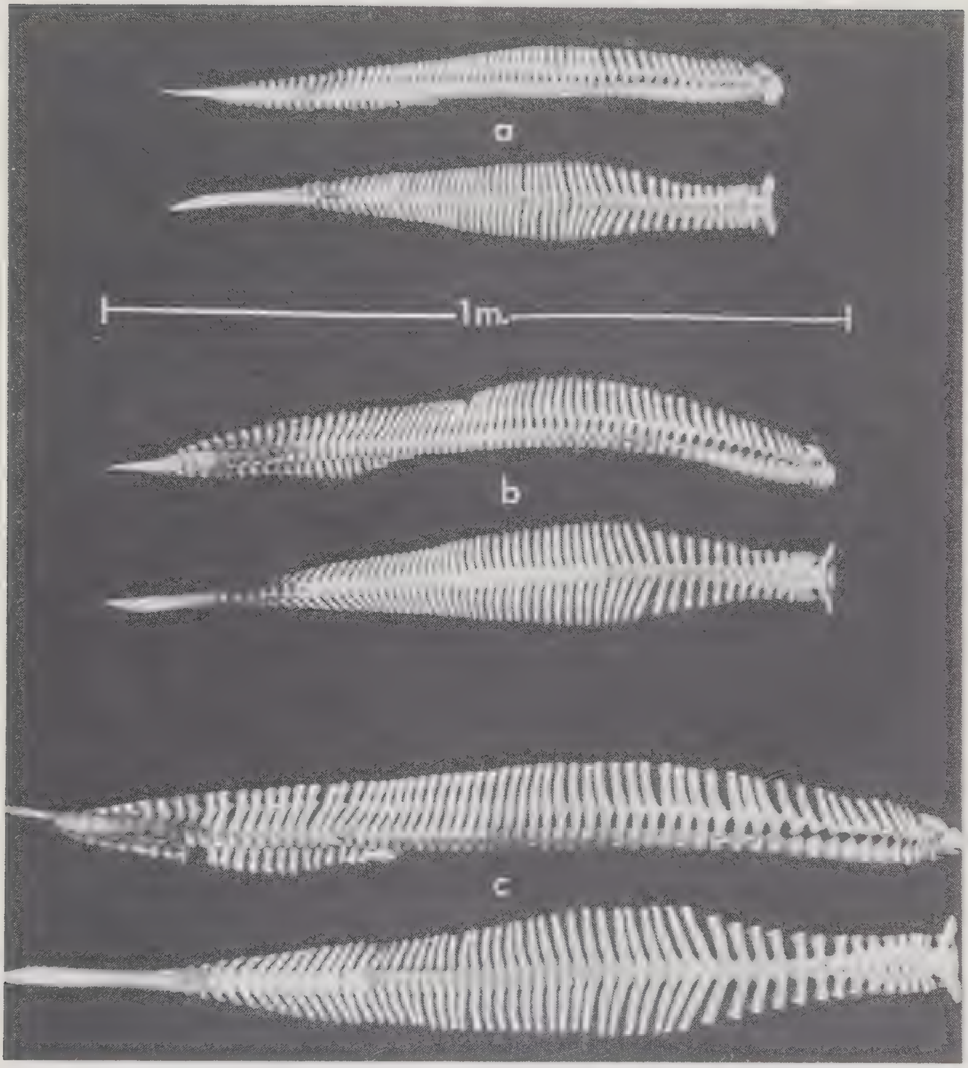


Figure 26. Developmental series of the postcranial axial skeleton of spotted porpoise: (a) LACM no. 27431, sex unknown, one layer, Class II.5; (b) USNM no. 395612, female, 2 layers. Class III; (c) USNM no. 395387, sexually immature male, 6 layers, Class IV (continued).

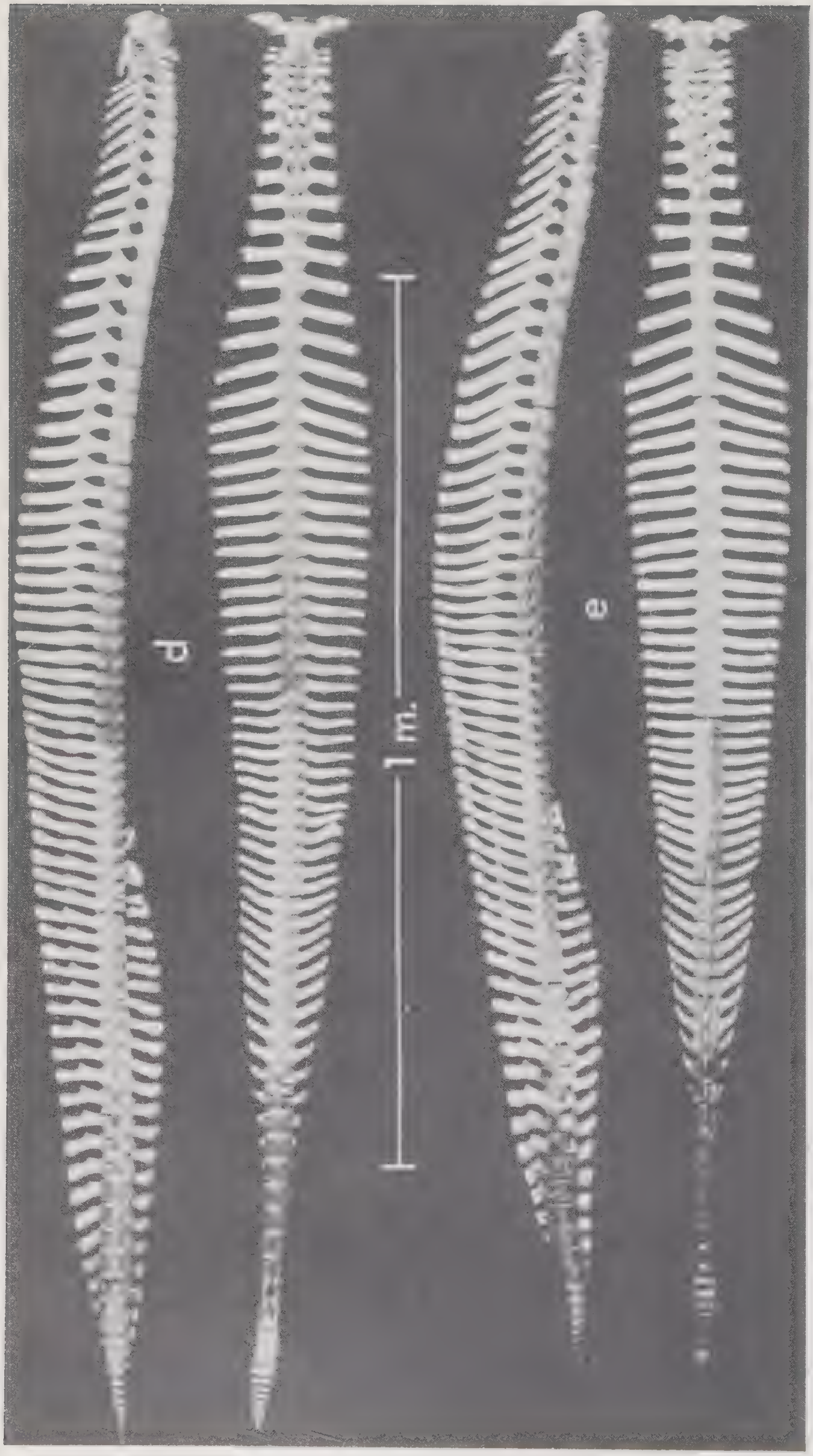
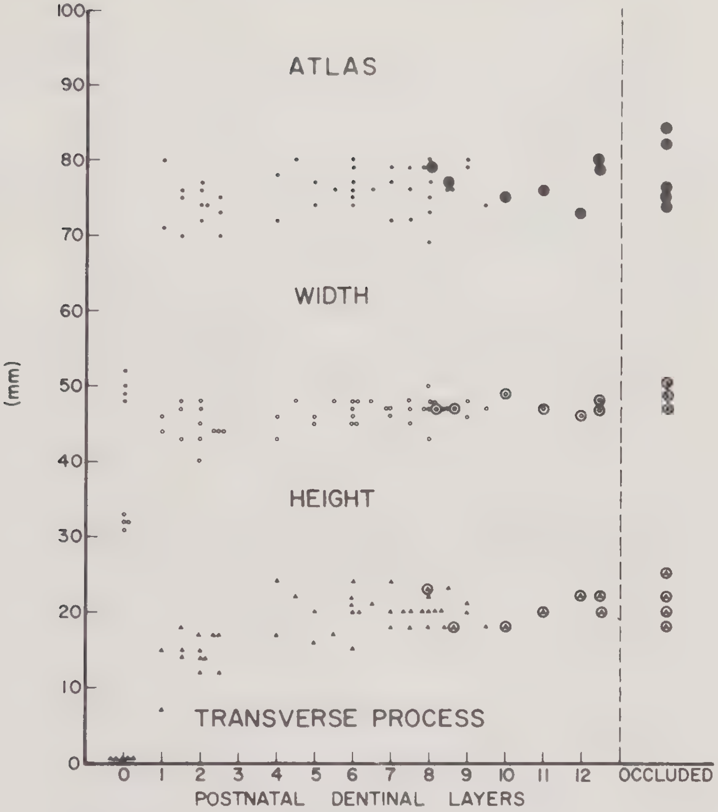


Figure 26. (continued). Developmental series of the postcranial axial skeleton of spotted porpoise: (d) USNM no. 395598, sexually mature but physically immature, 8 layers, Class V; (e) USNM no. 395338, sexually and physically mature female, 11 layers, Class VI.



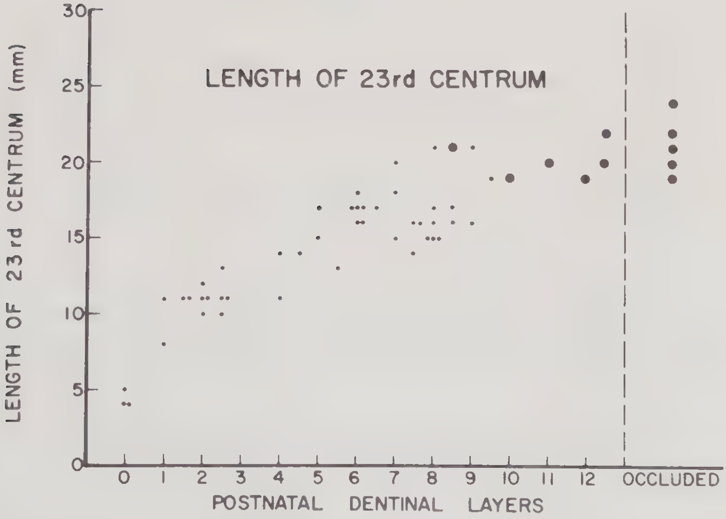


Figure 27. Development of vertebral column of spotted porpoise: scatterplots of measurements and meristics on number of dentinal layers. Small symbols are physically immature specimens; large symbols are mature (continued).

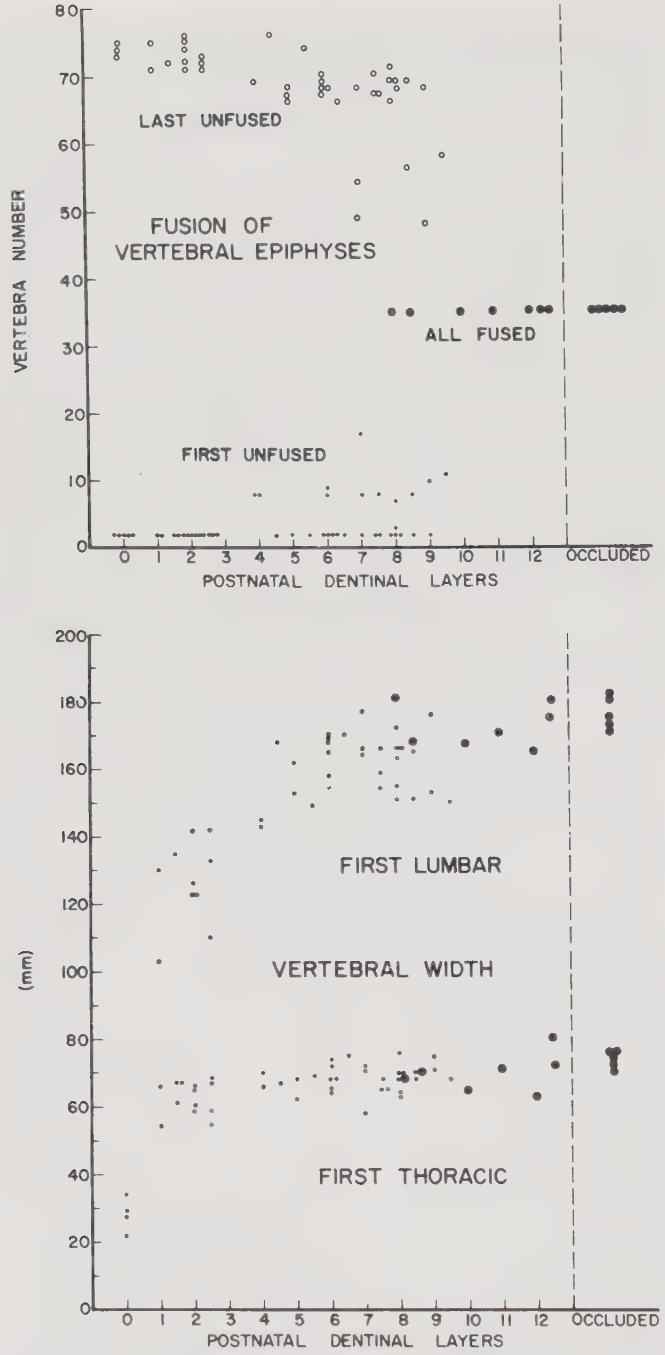


Figure 27 (continued). Development of vertebral column of spotted porpoise: scatterplots of measurements and meristics on number of dentinal layers. Small symbols are physically immature specimens; large symbols are mature (continued).

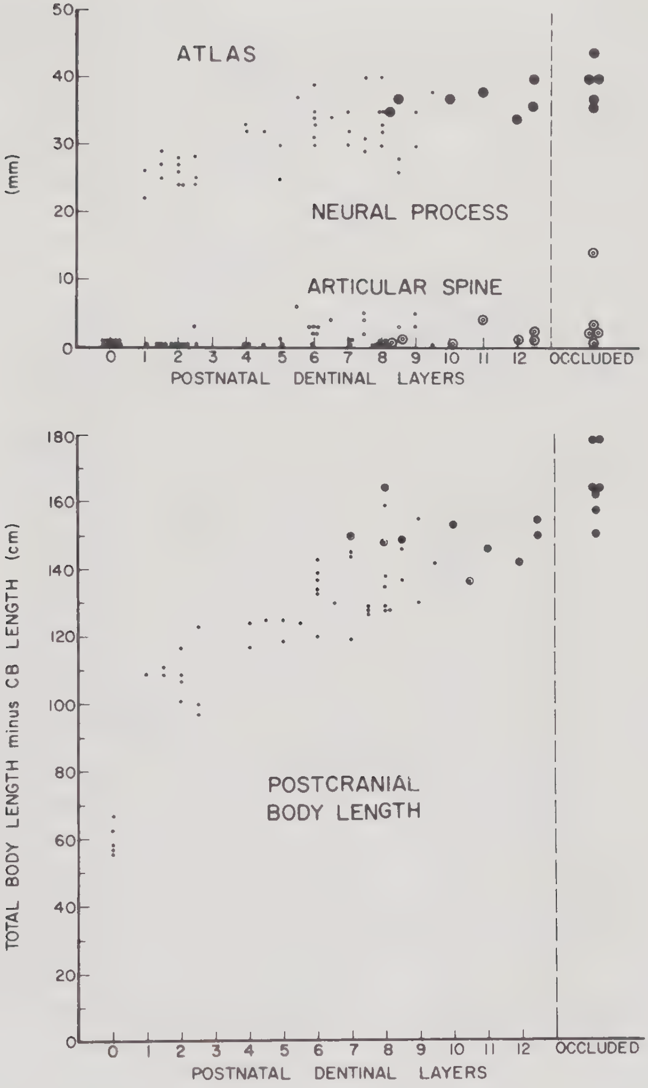


Figure 27 (continued). Development of vertebral column of spotted porpoise: scatterplots of measurements and meristics on number of dentinal layers. Small symbols are physically immature specimens; large symbols are mature.

Vertically perforating foramina occur in the center of the posterior portion of the vertebral column. The series of foramina lengthens during early development as progressive ossification encloses more vessels, moving the average position of the first enclosed opening forward one or two vertebrae. Stability is reached by Class II.5 (one layer in the dentine).

The vertebral ribs (fig. 28) reach adult shape in Class II.5. At birth the capitula of the two-headed ribs (first 4 to 6) are weakly developed, and there is a nearly insensible gradation from the two-headed condition to ribs with a tuberculum only. The hindermost three or four ribs at birth are very slender, and S-shaped to varying degree. The recurvature of the posterior ribs disappears by Class II.5, and they become proportionately more massive proximally. Similar development occurs in the sternal ribs, with adult shape achieved by Class II.5. Both vertebral and sternal ribs, however, continue to increase in absolute length and breadth at least until achievement of physical maturity and possibly beyond (fig. 29).

The shape and degree of ossification at birth of the manubrium of the sternum varies widely. Anterior fusion of the two wings may be complete or incomplete even until Class III is reached. A foramen may be present or absent. Adult shape of the manubrium is not reached until Class IV. Size of the foramen is extremely variable, but the tendency is toward closure with development. The foramen is closed in a significantly higher proportion of physically mature individuals than of immature individuals. After rapid increase in length and breadth up to Class IV, the manubrium continues to grow, albeit more slowly, at least until physical maturity is attained (fig. 29). The depth of the anterior notch also generally continues to increase, although some old individuals have relatively shallow notches.

Two mesosternal elements are ossified at birth. With development, the third mesosternal element, cartilaginous at birth, may or may not ossify. In some older individuals with three mesosternal elements, a small spherical ossification is present in the fourth, cartilaginous element. Thus old adults may possess two, three, or four mesosternal bones, depending on the course of postnatal ossification. The second mesosternal may consist of two side-by-side elements at birth, and traces of the suture of these elements is still visible in some mature specimens.

Fusion of the mesosternals to each other and of the first mesosternal to the manubrium begins in Class IV and proceeds to varying degrees of completeness, from fusion only of the manubrium and first mesosternal, to fusion of all four elements in some individuals. In some individuals, fusion may occur between the manubrium and first mesosternal and between the second and third elements but not between the first and second.

Anterior appendicular skeleton. The blade of the scapula (fig. 30) grows until physical maturity is attained and possibly beyond. The increase in height is more rapid than increase in length, causing the scapula to become progressively longer, proportionately, until the individual reaches physical maturity (fig. 31). The blade in the region of the coracovertebral angle thickens during adulthood and in old individuals the border may become keeled. The entire blade becomes more dished with age, and the accessory spines in the infraspinal fossa become more pronounced. In physically mature animals, the spines on the subscapular surface develop tuberose, posteriorly-directed ridges (fig. 30).

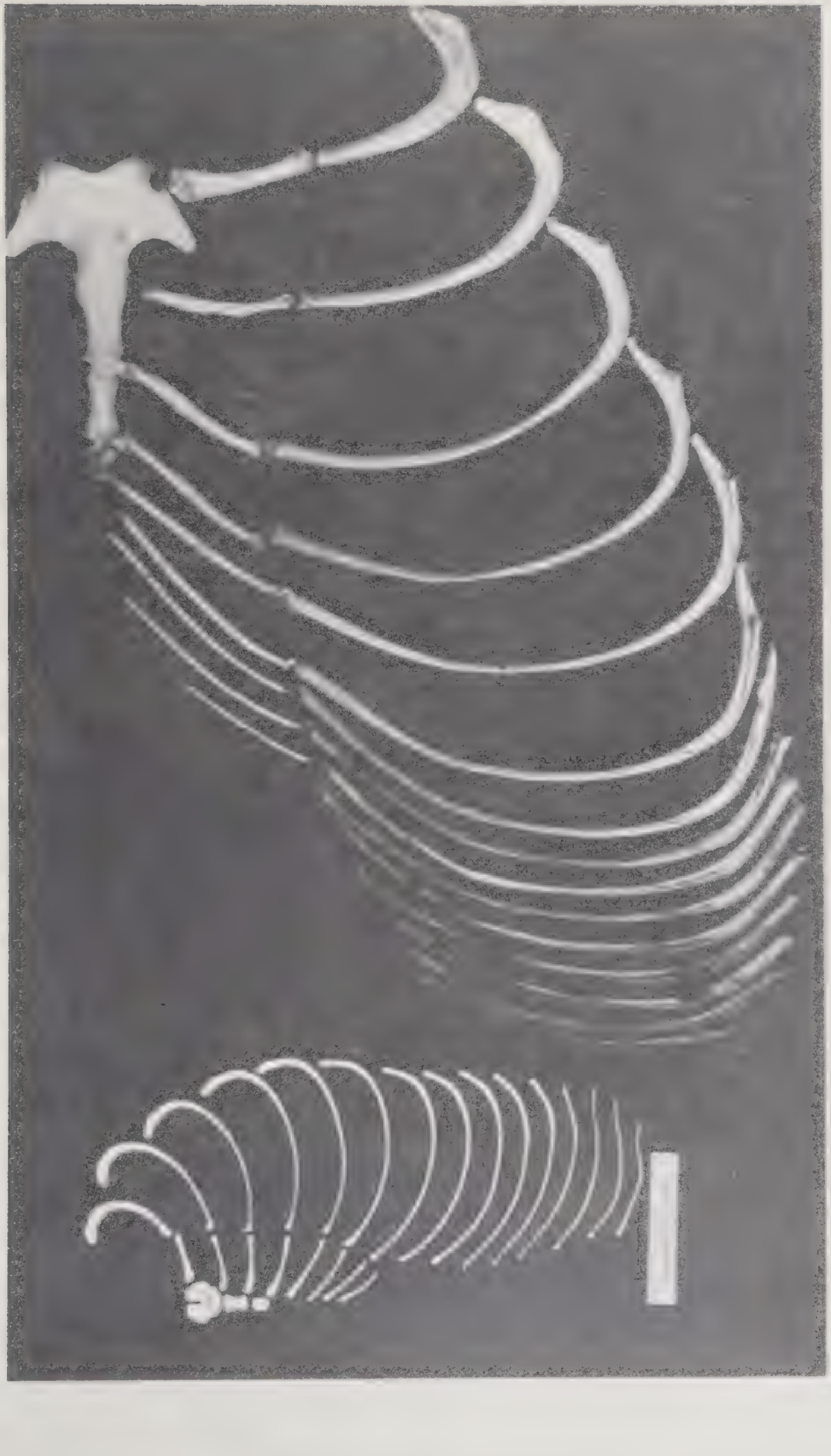
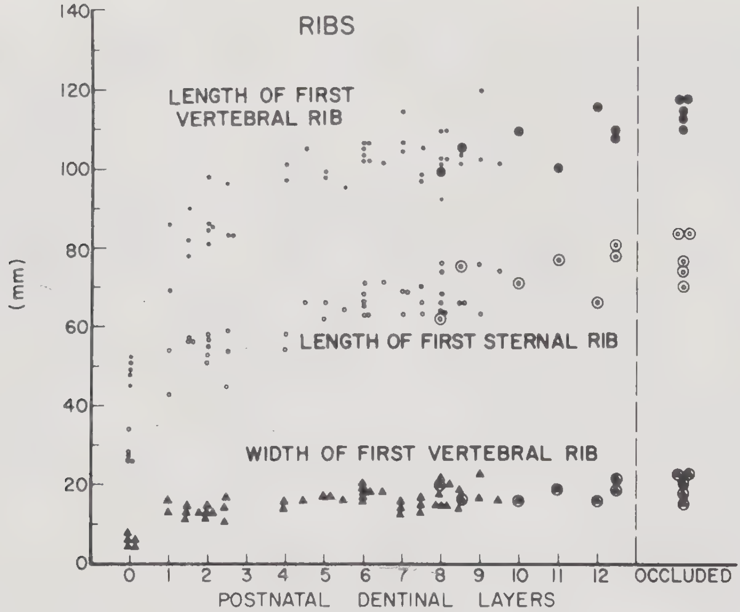


Figure 28. Ribs and sternae of neonatal (left) and physically mature (right) spotted porpoise (specimens *a* and *e* in figure 26).



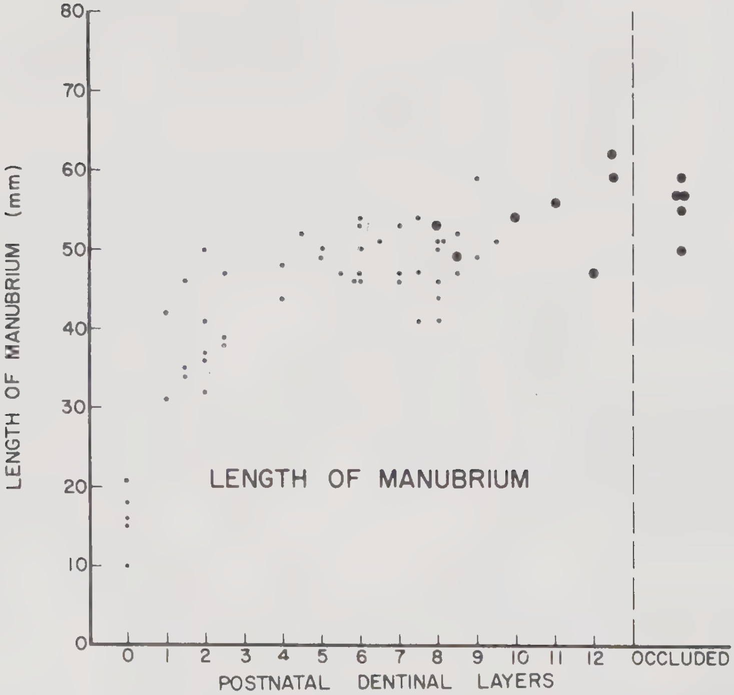


Figure 29. Development of ribs (top) and manubrium (bottom) of spotted porpoise: scatterplots of measurements and meristics on number of dentinal layers (continued).

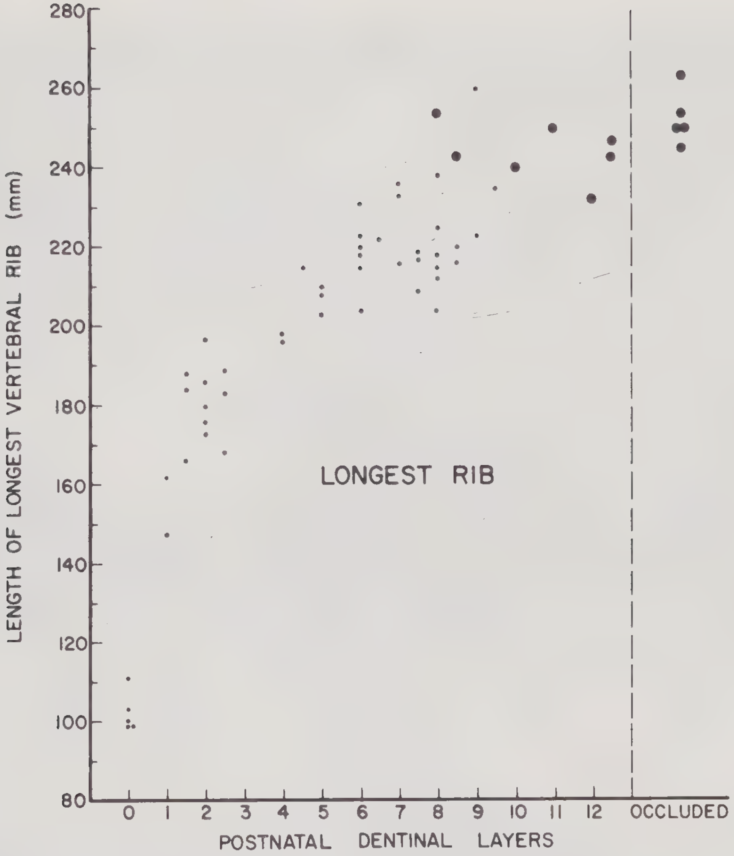


Figure 29 (continued). Development of longest rib of spotted porpoise: scatterplots of measurements and meristics on number of dentinal layers.

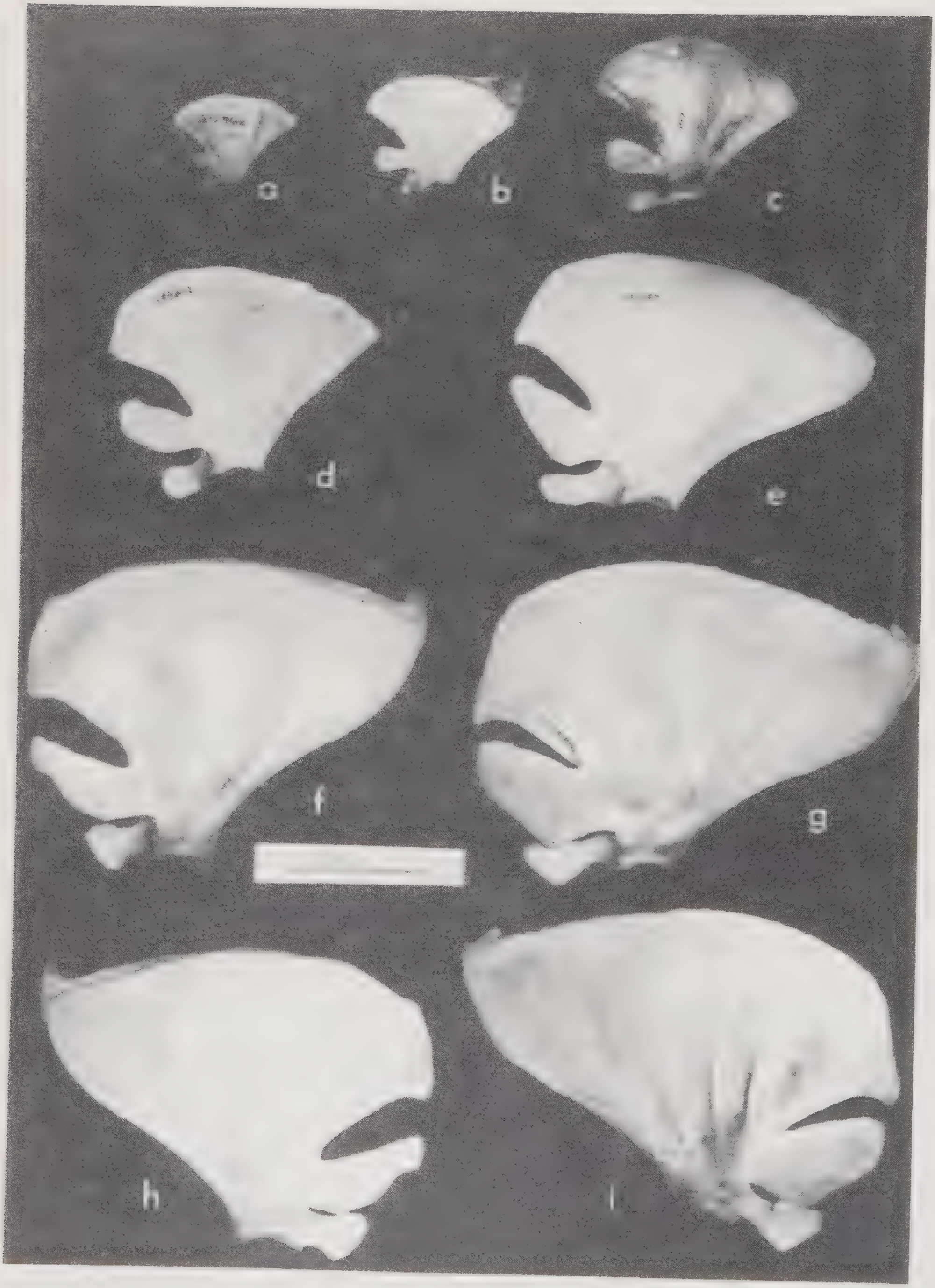


Figure 30. Scapulae of spotted porpoise: (a-g) external views of scapulae of developmental series in figure 35, (h and i) mesial views of scapulae of Class V and VI specimens, illustrating development of tuberose ridges.

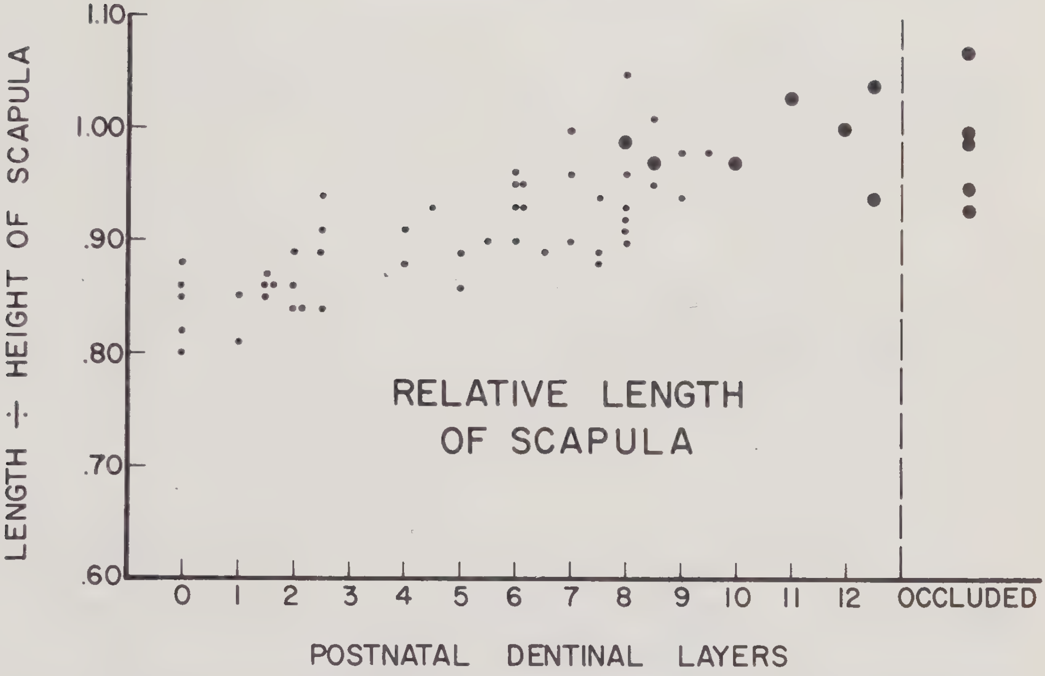


Figure 31. Development of scapula of spotted porpoise: scatterplot of relative length on number of dentinal layers.

The highly variable coracoid and metacromion processes reach adult shape in Class IV animals but continue to grow at a reduced rate into physical maturity.

The forelimb (fig. 32) develops rapidly after birth, and the number of osseous elements increases, to a near-adult shape by Class III. The forelimb then continues to grow slowly until physical maturity is reached. The olecranon process of the ulna, however, does not reach adult shape until Class V.

The usual complement of carpals at birth is five: a proximal row of three and a distal row of two. These correspond to the elements called by Fraser (1950) scaphoid, lunar, and cuneiform; and magnum and unciform, respectively. The element called trapezium by Fraser is unossified at birth. The small element called trapezoid by Fraser is only rarely present in specimens of any age (see section below on individual variation). The carpals increase in breadth at least until physical maturity is attained. The fifth metacarpal is absent at birth. In specimens of Class II.5, the trapezium and fifth metacarpal have become ossified, the latter to varying degree.

The first digit (thumb) has either no ossified phalanges or one at birth and throughout development. The numbers of ossified phalanges in the remaining digits undergo some change during development (fig. 33). Digit II has 6 or, most often, 7 at birth; in animals of Class III and older, the number is 7, 8, or occasionally 9. Digit III has 4 or 5 at birth; the prevailing number after Class II is 5, or occasionally 6. Digit IV has 1, 2, or, rarely, 3 at birth; the number thereafter with rare exception is 2. There are no ossified phalanges on digit V at birth. After ossification of the fifth metacarpal, a single phalanx may

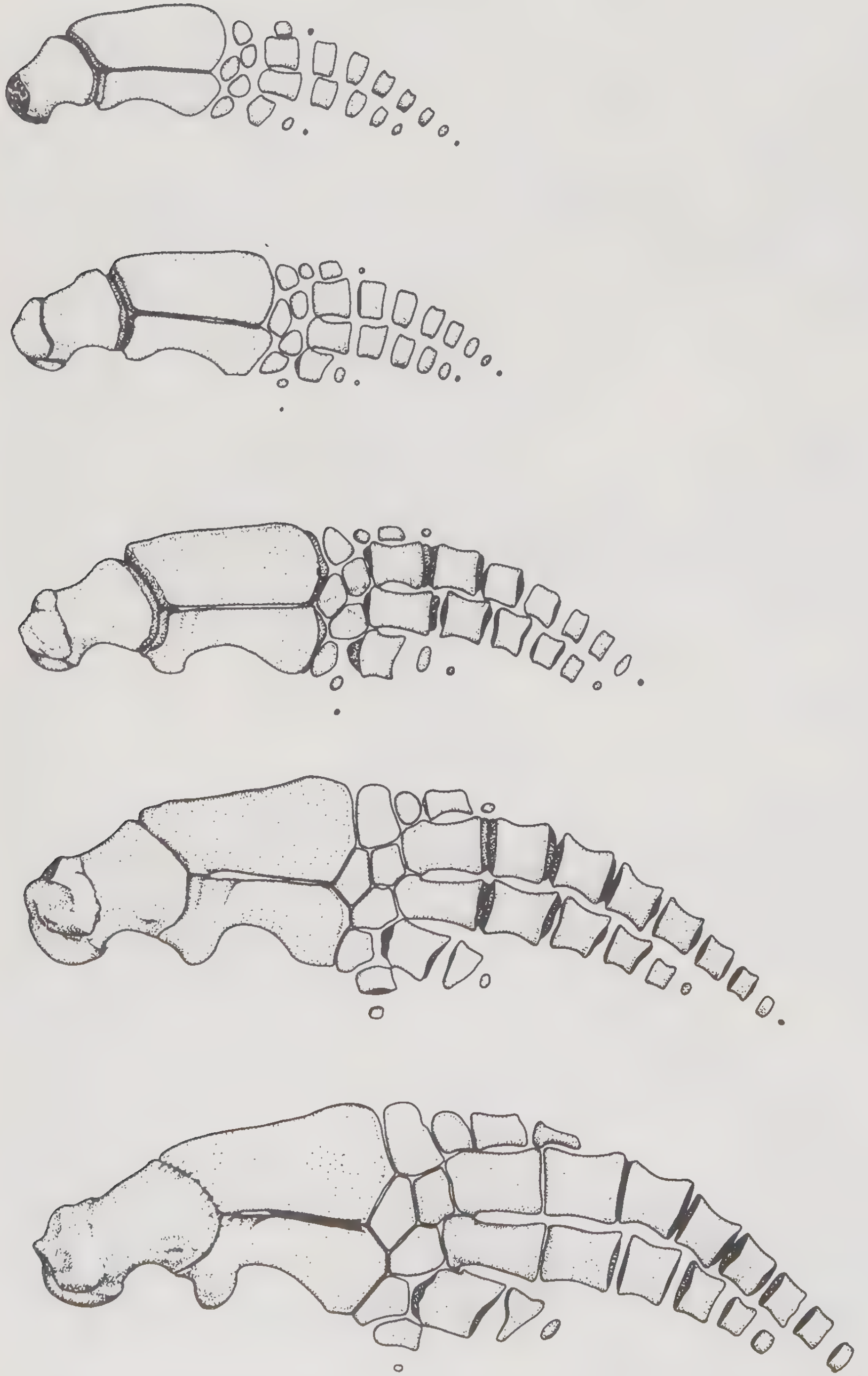


Figure 32. Developmental series of forelimb skeleton of spotted porpoise: (top to bottom) Class II, Class II.5, Class III, Class IV, Class VI.

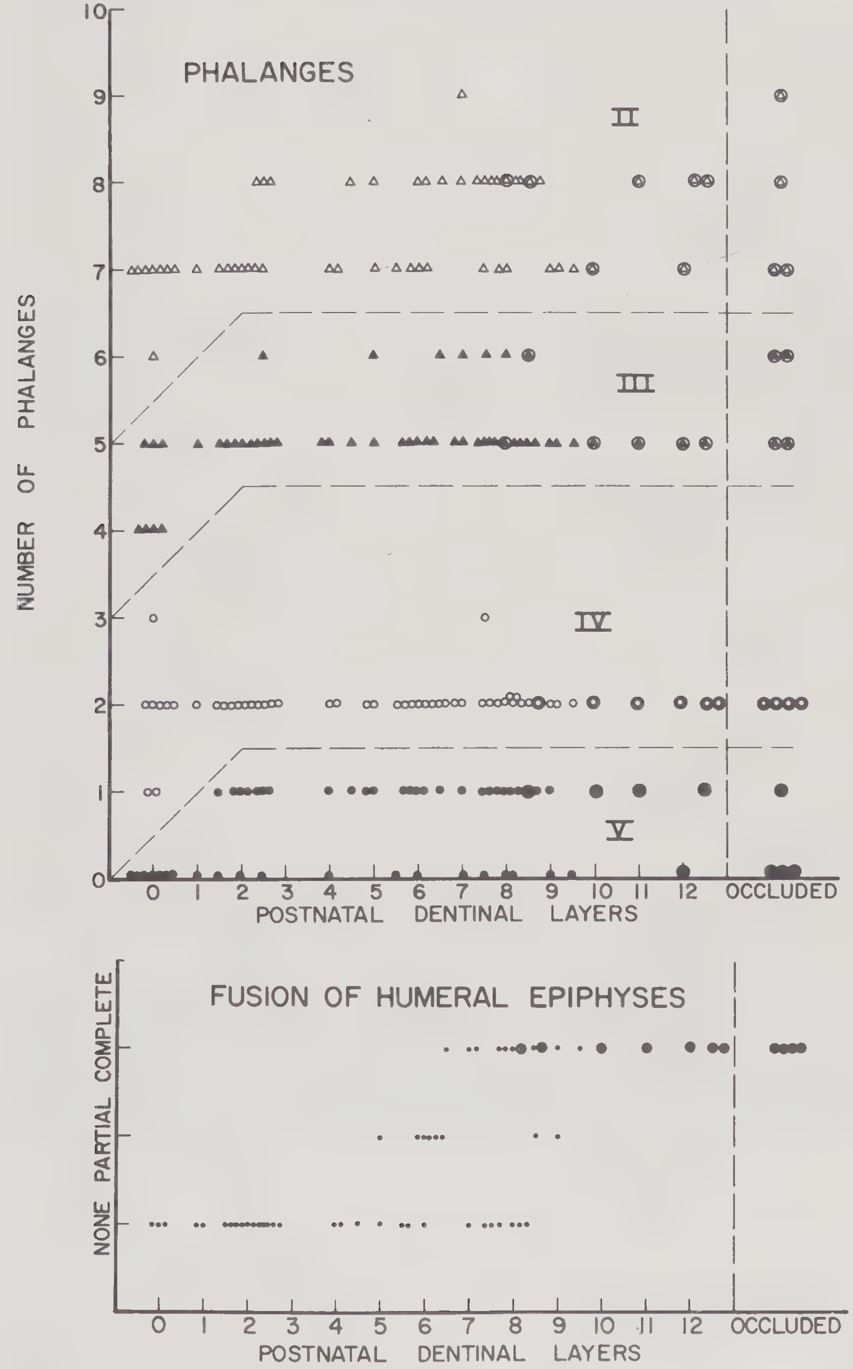


Figure 33. Development of manus of spotted porpoise: scatterplots of number of ossified phalanges on digits II-V (top) and degree of fusion of humeral epiphyses (bottom) on number of dentinal layers.

be added. The usual formulas at birth and in adulthood, then, are respectively: I-0 or 1, II-7, III-4 or 5, IV-1 or 2, V-0; and I-1 or 2, II-7 or 8, III-5 or 6, IV-2, V-1 or 2.

The epiphysis of the humerus is unossified at birth. In Class II.5 specimens it is ossified, and fusion to the humerus begins in Class IV (fig. 33). Fusion is completed on the average sooner than fusion of the vertebral epiphyses, and all "physically mature" animals have completely fused humeral epiphyses. Fusion of other elements of the forelimb (ulna to the radius, carpals to each other and/or to metacarpals, metacarpals to phalanges, phalanges to each other) may occur in physically mature specimens.

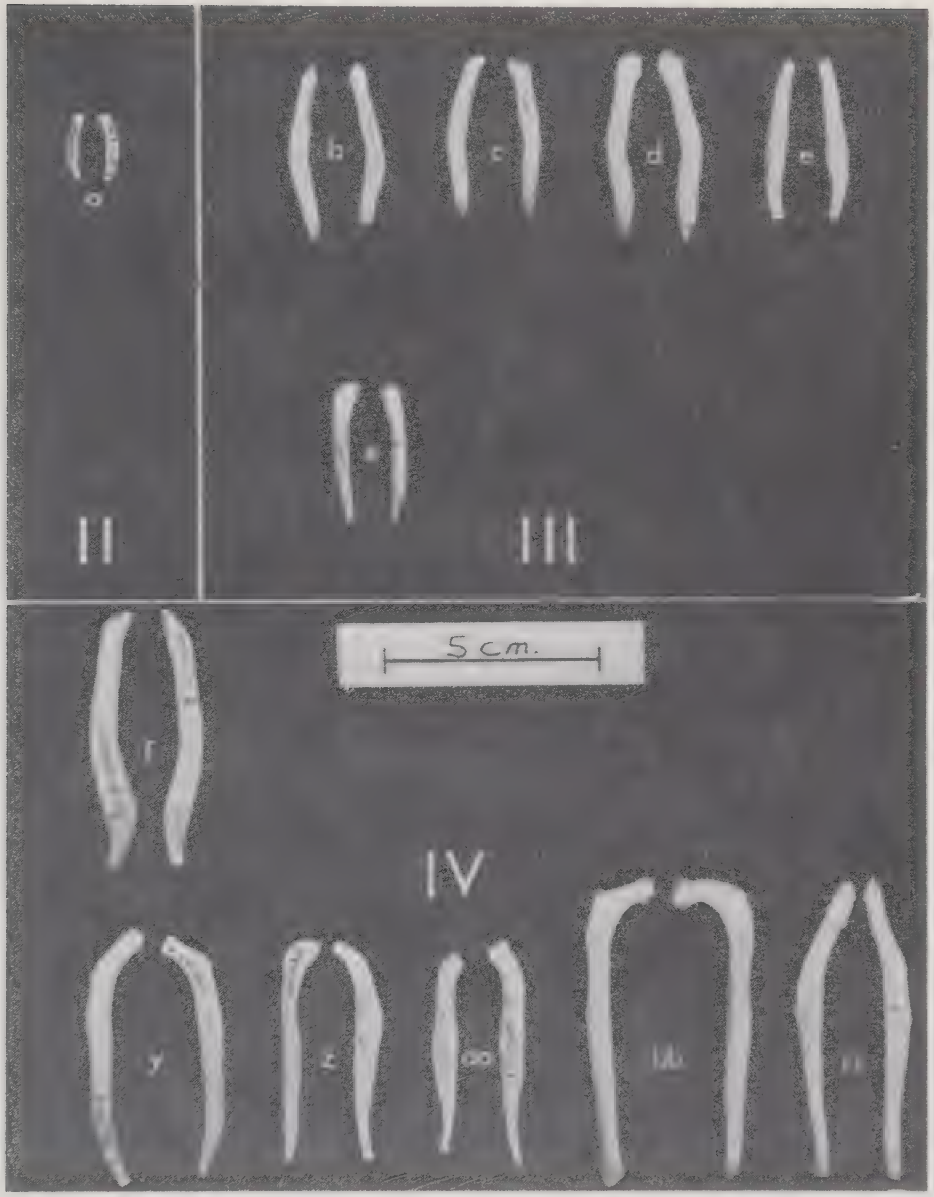
Posterior appendicular skeleton. The size and shape of the pelvic rudiments (fig. 34) differ between males and females, and the course of development and adult form and size in both sexes are extremely variable. In some specimens they are not yet ossified at birth. Some adult females have smaller, less complex pelvic bones than do some subadults.

Summary. The postcranial skeleton lags far behind the skull in postnatal development (compare curves in fig. 35 with those in fig. 25), with the exception of its anteriormost elements (atlas, axis, cervicals, first ribs), which reach adult size in subadult animals, albeit continuing to grow at a very slow rate thereafter. Of the remaining elements, the scapula, vertebral centra, and longest ribs show greatest and most protracted postnatal growth, continuing to grow possibly after physical maturity has been attained. The sample of physically mature specimens with determinable number of tooth layers is too small to determine with certainty whether or not growth continues beyond the onset of physical maturity.

Criteria for selection of adult specimens

Much of the taxonomy of Cetacea is of necessity based on skulls only, with little or no correlated data on external characters, reproductive condition, or the postcranial skeleton. When assessing variation in a series of such skulls, a decision must be made as to which specimens to consider effectively adult. The above analyses of developmental variation provide, for the spotted propoise, a basis for such a decision.

Consideration of the growth curves for cranial measurements leads to the conclusion that, except for the braincase and internal nares, the skull reaches adult proportions when about four layers have been laid down in the dentine, as much as two layers before the onset of sexual maturity, and four or more layers before attainment of "physical maturity." Thus, skulls of subadult specimens with 5 layers or more may be safely included in "adult" series, provided that allowance is made for growth of the braincase and nares, which continue at least until attainment of physical maturity. Regression analysis (two-way analysis of variance) of variation in "height of braincase," the cranial measurement most subject to age variation, shows that only about 11% of the variance (r^2) in the present sample of specimens with five or more postnatal dentinal layers is caused by age. This variation is only of consequence when comparing a very young skull with a very old one, where the expected difference owing to age is about 5%. The same applies to developmental variation in width of the internal nares. For purposes of analyses below of sexual, individual, and geographical variation of quantitative cranial characters, all specimens with five or more dentinal layers are included in the series. When teeth


b
c
d
e
II
III
5 cm.
r
IV
y
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aa
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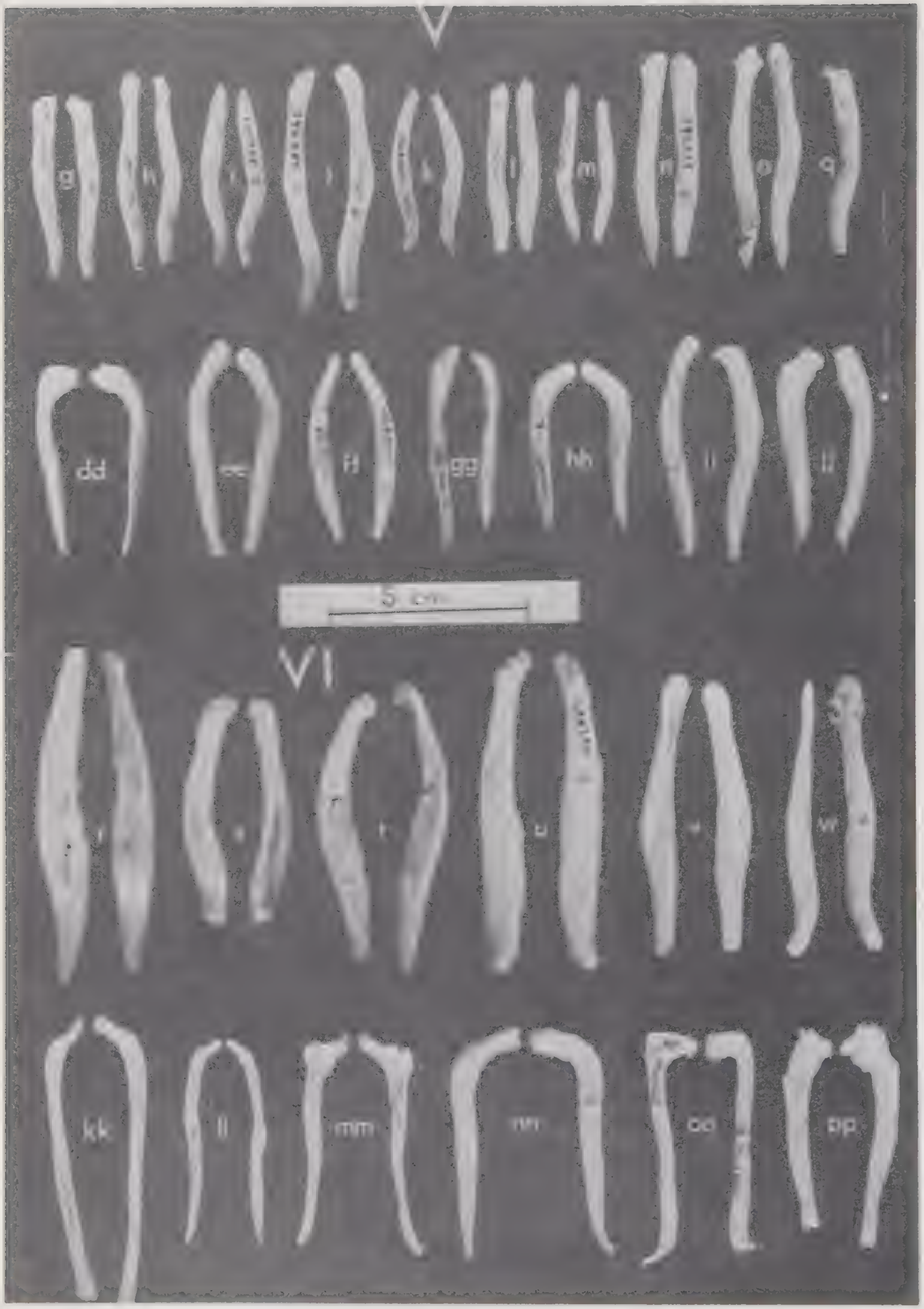
Figure 34. Pelvic rudiments of spotted porpoise, Class II to Class IV. For each class, males are above, females below (continued).


V
g
h
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jj
5 cm
VI
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s
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Figure 34 (continued). Pelvic rudiments of spotted porpoise, Classes V and VI. For each class, males are above, females below.

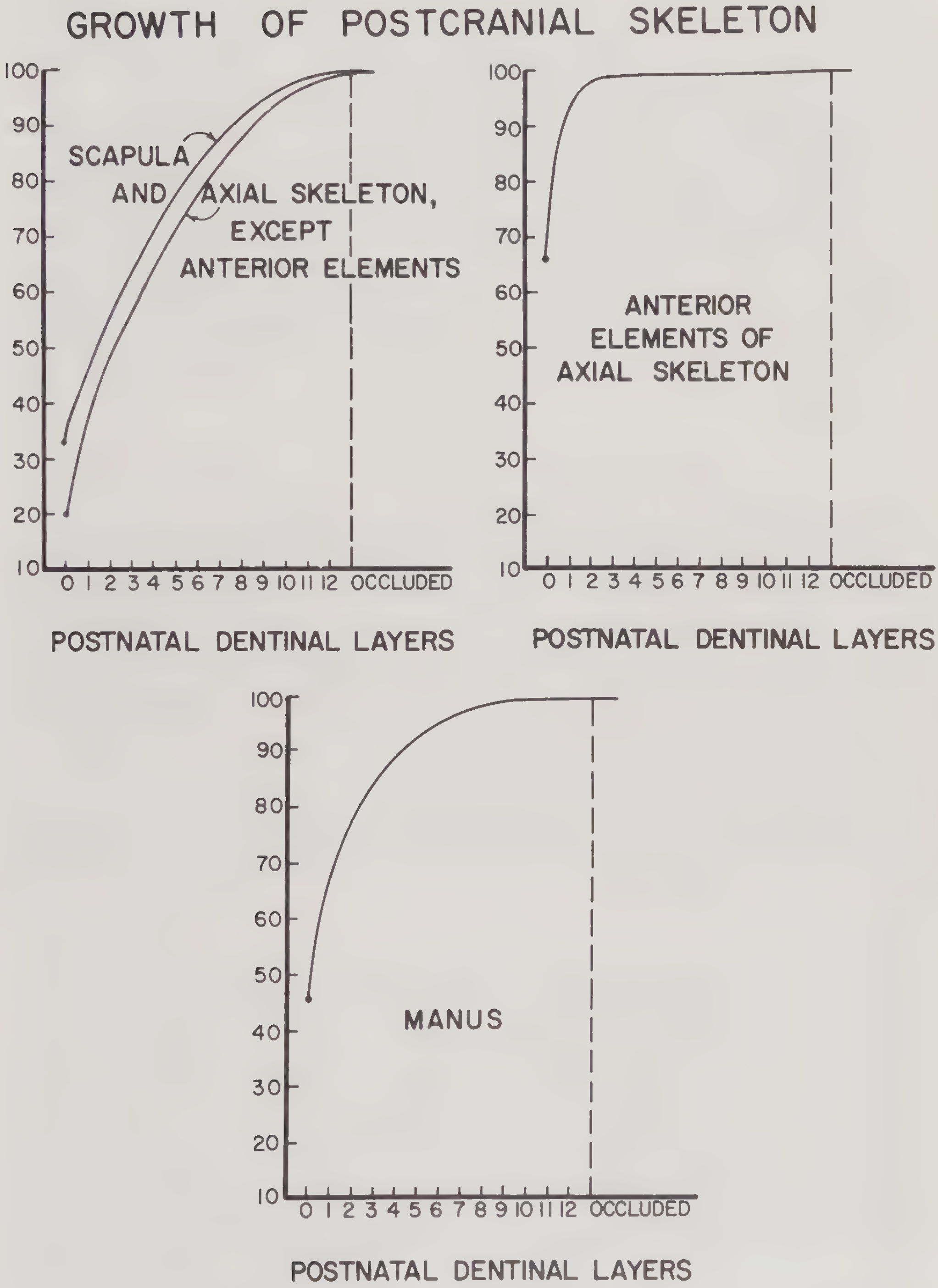

Figure 35. Growth of postcranial skeleton of spotted porpoise based on average growth rates.

were not sectioned, skulls were considered "adult" that exhibited distal fusion of the premaxillaries and maxillareis, a feature closely associated with attainment of sexual maturity (Dailey and Perrin, 1973). As no developmental variation was found for tooth counts, specimens of all ages are included in the series examined for tooth counts.

Which specimens to include in consideration of adult variation in quantitative postcranial skeleton characters is another matter. The protracted growth of the postcranial skeleton makes it advisable to include in an adult series only physically mature specimens (those with fused vertebral epiphyses), as variation owing to growth beyond attainment of physical maturity, if indeed it exists, is probably inconsequential. Even within a mature series, however, variation should be evaluated against the possible developmental component. This has been done here. As for the skull, the inclusiveness of series considered with respect to qualitative characters is determined on the basis of the descriptive accounts of developmental variation.

Sexual Dimorphism

Although sexual differences in the skeleton have been clearly demonstrated for some cetaceans (for example, by Moore, 1968, for certain of the ziphiids), this has not been encountered in any delphinid. Fischer (1881) examined the skulls of two female and two male specimens of *Delphinus delphis* and concluded that males have longer, more regularly tapering rostra less dilated at midlength, more elevated cranial crests, more ovoid posttemporal fossae, and higher crania than females. These conclusions, however, are not to be taken seriously, being based on such a small sample. Similar findings by Fischer for *Tursiops* based on four male and four female specimens were later refuted by True (1889), both on the basis of reexamination of Fischer's data and on the basis of examination of an additional series of 21 skulls; he concluded (p. 37) that variation in cranial proportions is "of little value in determining the sex."

The purpose of this section is to examine sexual variation in a large series of specimens. Dimorphism was detected only in the braincase, feeding apparatus, and postcranial skeleton.

Cranial skeleton

Braincase. The braincase of the male is on the average larger than that of the female. Mean internal length of the cranium (No. 18 in table 9) is greater for males both absolutely and as a percentage of condylobasal length. When expressed as percentage of parietal width, braincase length is not significantly different for males and females, indicating that the difference is one of size, not of proportion. G. Sacher (personal communication) measured the cranial volume of two adults and two near-term fetuses each of males and females from the present series with a direct method and found an average difference in volume of approximately 10%. Externally, the greater length of the male cranium is reflected in greater exposure of the frontals. There is great variation and overlap between the sexes.

Feeding apparatus. The rostra of adult females are on the average longer and more attenuate than those of males, precisely the reverse of Fischer's (1881) findings for *Delphinus* and *Tursiops* based on inadequate series. The dimorphism becomes more pronounced with age. For the full series of 31 females and 32 males (table 9), the average difference is significant at $\alpha = 0.05$ only for Rostrum tip to internal nares (no. 9) and Length of upper tooth row (no. 32) expressed as percentage of condylobasal length; and Rostrum tip to external nares (no. 8), Length of upper tooth row (no. 32), Length of lower tooth row (no. 37), and ramus length (no. 38) expressed as percentage of parietal width. The last four items reflect also the sexual difference in cranial dimensions. A scatterplot of rostral width at 3/4 length (no. 7) on rostral length (no. 2) for 15 physically mature specimens (7 males and 8 females, all physically mature), however, demonstrates clearly the existence of dimorphism in rostral proportions (fig. 36). The means of the ratio between these two measurements are significantly different at $\alpha = .05$; $\bar{x}$ male = 7.37 ± 0.40 (2 x S.E.), $\bar{x}$ female = 8.55 ± 0.36, with no overlap between males and females for the 15 physically mature specimens.

Postcranial skeleton

Width of the first vertebral rib (no. 87) is greater in males. Males more often possess a phalanx in the first digit (no. 114). Dimorphism in the pelvic rudiments was illustrated above (fig. 34) in the section on development. The size and shape of the pelivcs are extremely variable but the male pelvic is more often than not rod-shaped and the female L-shaped to greater or lesser degree. The male pelvic is clearly larger on the average.

Individual Variation

A knowledge of the range and nature of individual osteological variation within what is known or presumed to be an inbreeding unit is of prime importance to the evaluation of differences between samples that must precede taxonomic decision making. With very few exceptions (*Pseudorca crassidens*: Yamada, 1956; *Delphinus delphis*: Kleinenberg, 1956 and Cadenat, 1959) this necessary basic knowledge does not exist for delphinid species.

In this study, I collected two series of complete skeletal specimens of spotted porpoise from single seine net sets, one of 33 animals and the other of 28 (table 10). These samples from presumably inbreeding groups are referred to below as Set 2 and Set 6.

Cranial skeleton

Braincase. In ventral view, the occipital condyles are developed to varying degree. The anterior margins may be sharply delineated and rounded, or pointed in outline, or may grade imperceptibly into the basoccipital plate. The channel between them may be relatively long and narrow with parallel sides, triangular, or even closed. Similarly, the lateral and dorsal margins of the condyles are delineated to varying degree. Sculpturing of the occipital bone above the condyle varies from a faint, shallow indentation to a deep furrow. The medial occipital ridge may be absent or present as a thick prominence. It may extend anteriad to join the frontal crest on the midline of the skull.

Table 9. Skeleton measurements and meristics differing between male and female adult offshore spotted porpoise, with statistical comparisons of means

Variable	Unit	Males					Females					Absolute value of significant t, at $\alpha = .05$		
		Number of specimens	Range	Mean	Standard deviation	Coefficient of variability	Number of specimens	Range	Mean	Standard deviation	Coefficient of variability	Absolute measurements	Expressed as percentage of condylobasal length	Expressed as percentage of parietal width
1. Condylobasal length	mm	32	360-408	387.9	11.21	2.89	31	356-415	390.9	14.52	3.71			
8. Rostrum tip to external nares	mm	32	245-291	267.4	10.27	3.84	31	246-298	274.3	13.93	5.08			3.35
9. Rostrum tip to internal nares	mm	32	249-286	269.8	9.63	3.57	31	243-304	275.7	13.70	4.97		2.99	
17. Braincase height	mm	32	89-106	97.5	4.12	4.23	31	87-102	95.2	3.83	4.03		4.59	
18. Braincase length	mm	32	112-123	117.8	2.98	2.53	31	109-120	114.6	2.84	2.48	4.36		
32. Upper tooth row length	mm	32	180-216	199.1	8.53	4.28	31	186-226	204.8	11.47	5.60		3.39	3.44
33. Upper left teeth	no.	42	37-46	41.3	2.47	5.99	39	37-47	41.4	2.14	5.16			2.88
34. Upper right teeth	no.	42	37-46	41.1	2.20	5.34	40	37-48	41.8	2.32	5.55			2.85
87. First vertebral rib width	mm	6	20-21	20.7	0.52	2.50	6	16-20	17.5	1.76	10.06	4.27		
114. Digit I phalanges	no.	35	0-1	0.9	0.28	31.11	29	0-1	0.6	0.49	81.67	3.07		
120. Pelvic length (left)	mm	5	58-86	75.0	11.14	14.85	5	52-70	58.0	7.04	12.13	2.88		

Table 10. Skeleton measurements and meristics for two single-school series of spotted porpoise (continued)

Variable	Unit	Set 2					Set 6				
		Number of specimens	Range	Mean	Standard deviation	Coefficient of variability	Number of specimens	Range	Mean	Standard deviation	Coefficient of variability
1. Condylobasal length	mm	22	356-411	388.4	14.90	3.84	19	369-406	390.2	8.35	2.14
2. Rostrum length	mm	22	210-248	230.9	10.61	4.59	19	214-247	232.2	7.76	3.34
3. Rostrum width at base	mm	22	77-91	82.4	3.71	4.50	19	77-86	81.0	2.36	2.91
4. Rostrum width at 60 mm	mm	22	49-61	54.6	3.09	5.66	19	52-61	55.6	2.71	4.88
5. Rostrum width at midlength	mm	22	35-44	40.1	2.29	5.70	19	36-48	40.8	3.10	7.60
6. Premaxillary width at rostral midlength	mm	22	19-27	21.7	1.91	8.78	19	18-27	22.0	2.47	11.24

7. Rostrum width at 3/4 length	mm	22	24-31	27.5	2.11	7.66	19	24-36	28.6	2.91	10.19
8. Rostrum tip to external nares	mm	22	245-294	270.5	13.39	4.95	19	248-283	269.8	9.06	3.36
9. Rostrum tip to internal nares	mm	22	243-293	272.0	13.24	4.87	19	250-285	272.5	9.33	3.42
10. Preorbital width	mm	21	134-154	145.0	4.28	2.96	19	137-154	145.0	3.45	2.38
11. Postorbital width	mm	21	152-173	163.1	4.47	2.74	19	159-173	163.4	3.25	1.99
12. Least supraorbital width	mm	22	133-154	144.1	4.70	3.26	19	138-151	143.5	3.32	2.32
13. External nares width	mm	22	37-44	40.7	1.61	3.95	19	37-46	41.8	2.02	4.82
14. Zygomatic width	mm	22	153-174	161.6	4.33	2.68	19	158-174	163.2	3.60	2.21
15. Greatest width of premaxillaries	mm	22	61-68	64.9	2.11	3.26	19	60-69	64.5	2.70	4.18
16. Parietal width	mm	22	129-146	137.4	4.76	3.46	19	129-146	137.3	3.89	2.83
17. Braincase height	mm	22	87-105	95.1	3.90	4.09	19	94-104	97.3	2.71	2.78
18. Braincase length (M)	mm	11	112-122	117.2	3.43	2.93	12	115-121	118.4	1.83	1.55
(F)		11	109-120	115.6	2.69	2.33	7	111-117	114.4	1.99	1.74
19. Posttemporal fossa length	mm	22	60-75	67.4	3.79	5.62	19	64-77	69.1	3.42	4.96
20. Posttemporal fossa width	mm	22	47-58	51.8	2.99	5.76	19	48-63	53.9	3.16	5.86
21. Temporal fossa major diameter	mm	22	36-42	39.0	1.70	4.37	19	37-44	39.4	1.89	4.81
22. Temporal fossa minor diameter	mm	22	18-26	22.2	1.89	8.54	19	20-25	22.6	1.12	4.93
23. Projection of premaxillaries	mm	19	14-25	17.8	2.94	16.50	16	12-21	17.3	2.36	13.62
24. Nasals to crest (M)	mm	11	20-35	27.0	5.20	19.25	12	22-34	26.4	2.94	11.12
(F)		11	18-29	23.5	3.33	14.13	7	20-27	24.1	2.27	9.39
25. Orbit length	mm	22	44-51	47.1	1.73	3.66	19	44-50	46.7	1.83	3.91
26. Antorbital process length	mm	22	30-38	34.8	2.43	6.98	19	30-38	34.9	1.94	5.56
27; Internal nares width	mm	22	42-50	45.6	2.17	4.76	19	44-53	47.1	2.26	4.79
28. Pterygoid length	mm	22	55-70	61.8	4.83	7.82	19	58-76	64.7	4.71	7.29
29. Occipital overhang	mm	22	0-9	3.7	2.68	71.79	19	2-6	3.5	1.31	37.06
30. Bulla length	mm	22	29-31	29.8	.45	1.52	19	29-33	30.1	.96	2.97
31. Periotic length	mm	22	26-28	26.6	.48	1.80	19	25-29	26.9	1.04	3.87
32. Upper tooth row length	mm	22	180-220	200.7	10.25	5.11	19	187-219	202.3	8.44	4.17
33. Upper left teeth	no.	32	37-45	41.4	2.25	5.45	27	37-48	41.3	2.66	6.44
34. Upper right teeth	no.	32	38-45	41.3	2.23	5.41	27	37-47	41.4	2.71	6.54
35. Lower left teeth	no.	33	36-45	40.5	2.06	5.09	28	34-46	40.1	2.72	6.77
36. Lower right teeth	no.	33	37-45	40.7	2.02	4.96	28	34-45	40.2	2.47	6.14
37. Lower tooth row length	mm	21	177-220	196.5	9.86	5.02	19	180-210	194.3	8.37	4.31
38. Ramus length	mm	21	296-347	327.4	14.52	4.43	19	306-343	328.3	8.56	2.61
39. Ramus height	mm	22	51-59	56.3	1.73	3.07	19	53-60	57.3	1.89	3.29
40. Mandibular fossa length	mm	22	90-116	103.8	5.61	5.41	19	98-114	104.4	4.36	4.18
41. Deviation from symmetry	degrees	22	3-10	8.1	1.72	21.21	18	5-9	7.7	1.14	14.84
42. Basihyal length	mm	20	25-33	29.4	2.14	7.27	18	27-32	29.1	1.41	4.84
43. Basihyal width	mm	19	29-42	34.5	2.65	7.70	18	29-39	33.9	2.84	8.36
44. Thyrohyal width	mm	19	15-19	17.5	1.17	6.71	18	14-20	17.5	1.47	8.37
45. Thyrohyal length	mm	19	46-60	53.5	2.95	5.51	18	43-62	53.4	4.88	9.13
46. Stylohyal width	mm	19	11-13	11.9	.85	7.10	18	11-13	12.0	.77	6.39

Table 10 (continued). Skeleton measurements and meristics for two-school series of spotted porpoise

Variable	Unit	Set 2					Set 6				
		Number of specimens	Range	Mean	Standard deviation	Coefficient of variability	Number of specimens	Range	Mean	Standard deviation	Coefficient of variability
47. Stylohyal length	mm	19	63-74	69.1	2.93	4.25	18	61-73	68.6	3.45	5.03
48. Thoracic vertebrae	no.	30	15-17	16.0	.61		25	15-17	16.1	.64	
49. Lumbar vertebrae	no.	28	17-23	20.0	1.53		19	18-22	19.7	1.15	
50. Caudal vertebrae	no.	27	36-42	38.1	1.54		18	36-41	38.8	1.22	
51. Total vertebrae	no.	23	79-83	81.0	1.15		21	79-83	81.2	1.00	
52. Fused cervical vertebrae	no.	6	2-3	2.2	.37		6	2-7	2.8	1.86	
53. Atlas width	mm	6	73-80	76.2	2.79	3.66	6	77-84	79.7	2.80	3.54
54. Atlas height	mm	6	46-49	47.3	1.03	2.18	6	47-50	48.0	1.26	2.64
55. Atlas lateral process length	mm	6	18-25	21.0	2.37	11.27	6	18-24	20.8	2.56	12.30
56. Atlas neural spine length	mm	6	30-40	35.8	3.49	9.73	6	35-44	38.7	3.33	8.60
57. Atlas dorsal ridge height	mm	6	1-4	2.5	1.05	41.96	6	1-4	2.3	1.03	44.26
58. Atlas dorsolateral spine length	mm	6	0-4	1.7	1.63	97.98	6	0-14	3.5	5.24	149.83
59. Axis lateral process length	mm	6	16-25	19.3	3.08	15.91	6	16-22	19.5	2.07	10.63
60. Cervical vertebrae incomplete	no.	6	0-1	.3	.47		6	0-1	.3	.47	
61. Greatest ventrolateral cervical process on	no.	6	6-6	.6	0		6	6-6	6.0	0	
62. First vertical foramen on	no.	33	55-61	57.5	1.64		28	55-59	57.5	1.20	
63. First vertebra with reduced metapophyses	no.	30	28-35	31.5	1.91		26	24-34	31.8	2.29	
64. Last transverse process on	no.	30	61-66	63.0	1.30		27	62-65	63.3	.72	
65. Last neural spine on	no.	30	67-71	68.3	1.09		27	67-70	68.5	.98	
68. First caudal with vertical spine	no.	30	56-63	60.6	1.57		27	59-64	61.2	1.19	
69. First thoracic neural spine length	mm	6	19-37	29.0	6.10	21.03	6	9-32	23.8	9.35	39.22
70. Second thoracic neural spine length	mm	6	32-43	39.2	4.36	11.12	6	34-44	39.0	3.85	9.86
71. Tenth thoracic neural spine length	mm	6	55-70	62.7	6.22	9.92	6	55-67	61.2	4.58	7.49
72. Last thoracic neural spine length	mm	6	67-78	72.2	4.02	5.57	6	63-76	69.3	5.54	7.99
73. First thoracic vertebra height (M)	mm	2	44-48	-	-	-	4	45-46	-	-	-
(F)		4	44-47	-	-	-	2	46-51	-	-	-
74. First thoracic vertebra width	mm	6	63-80	70.3	5.99	8.52	6	68-76	72.5	3.21	4.43
75. First lumbar vertebra height	mm	6	46-52	49.3	1.97	3.99	6	48-52	49.2	1.47	2.99
76. First lumbar vertebra width	mm	6	165-180	171.8	5.64	3.28	6	168-182	176.7	5.16	2.92
77. 23rd centrum length	mm	6	19-21	19.8	.68	3.46	5	21-24	21.8	1.17	5.35

78. Left vertebral ribs	no.	28	15-17	15.9	.63		21	15-17	16.0	.59	
79. Right vertebral ribs	no.	26	15-17	15.8	.61		20	15-17	16.1	.60	
80. Left 2-headed ribs	no.	33	4-7	5.5	.71		28	4-7	5.5	.74	
81. Right 2-headed ribs	no.	33	4-7	5.6	.66		28	4-7	5.4	.74	
82. Left floating ribs	no.	26	0-2	1.3	.53		20	0-2	1.0	.46	
83. Right floating ribs	no.	24	0-2	1.2	.48		20	0-2	1.1	.51	
84. Left sternal ribs	no.	24	9-11	9.4	.65		18	9-11	9.5	.62	
85. Right sternal ribs	no.	23	9-11	9.3	.65		19	9-11	9.5	.61	
86. First vertebral rib length	mm	6	100-119	111.3	7.06	6.34	6	105-113	109.5	2.81	2.57
87. First vertebral rib width (M)	mm	2	21-23	-	-	-	4	19-21	-	-	-
(F)		4	16-19	-	-	-	2	16-20	-	-	-
88. Longest vertebral rib length	mm	6	232-261	246.7	9.87	4.00	6	243-254	248.0	4.98	2.01
89. First sternal rib length	mm	6	66-79	73.8	4.71	6.38	6	70-83	76.3	4.59	6.01
90. Manubrium width	mm	6	79-97	87.5	7.87	8.99	6	73-92	83.8	6.18	7.37
91. Manubrium length	mm	6	47-62	55.8	5.12	9.16	6	49-59	55.3	3.88	7.01
92. Manubrium notch depth	mm	6	5-19	10.5	4.93	46.95	6	5-11	8.5	2.07	24.40
93. Manubrium foramen length	mm	6	0-4	1.7	1.97	117.98	6	0-11	6.2	4.07	66.00
94. Mesosternal elements	no.	6	2-3	2.8	.20		6	2-3	2.8	.37	
95. Mesosternals fused	no.	6	1-2	1.5	.50		6	1-3	1.5	.76	
96. Chevron bones	no.	23	26-33	29.7	1.79		16	28-32	30.5	1.03	
97. Chevron bones fused in first series	no.	6	2-3	2.5	.50		6	0-2	1.7	.75	
98. First chevron on	no.	29	41-47	43.7	1.49		21	41-46	43.6	1.16	
99. Last chevron on	no.	24	70-77	72.5	1.69		18	70-75	72.8	1.34	
100. First chevron length	mm	6	3-23	11.2	6.79	60.85	5	3-11	6.6	3.21	48.63
101. Longest chevron length	mm	6	40-48	43.2	2.86	6.62	6	41-48	45.8	2.64	5.76
102. Last chevron length	mm	5	2-4	2.8	.84	29.88	4	3-4	3.3	.50	15.38
103. Scapula height	mm	6	101-114	106.8	4.45	4.16	6	101-111	106.2	4.36	4.10
104. Scapula length	mm	6	99-118	108.3	6.25	5.77	6	100-110	103.2	3.60	3.50
105. Coracoid length	mm	6	28-33	29.8	1.72	5.77	6	26-38	31.0	4.00	12.90
106. Coracoid width	mm	6	10-30	19.0	6.99	36.77	6	15-24	18.5	3.39	18.33
107. Metacromion width	mm	6	24-46	38.8	7.99	20.56	6	29-47	40.7	7.17	17.64
108. Humerus length	mm	6	47-51	48.7	1.37	2.81	6	43-49	46.7	2.58	5.53
109. Humerus width	mm	6	33-36	33.8	1.17	3.46	6	33-35	34.2	.75	2.20
110. Radius length	mm	6	59-67	62.5	3.02	4.83	6	58-63	61.3	1.86	3.04
111. Radius width	mm	6	30-33	31.2	.98	3.15	6	29-33	30.7	1.63	5.32
112. Ulna length	mm	6	53-57	55.5	1.64	2.96	6	52-56	53.3	1.75	3.28
113. Carpal row width	mm	6	51-61	55.8	4.17	7.46	5	53-60	54.8	2.95	5.38
114. Digit I phalanges (M)	no.	2	1-1	-	-		4	0-0	-	-	
(F)	no.	4	0-1	-	-		2	0-0	-	-	
115. Digit II phalanges	no.	31	7-9	7.4	.62		23	7-8	8.4	.50	
116. Digit III phalanges	no.	31	4-6	5.1	.40		25	5-6	5.1	.28	
117. Digit IV phalanges	no.	30	2-2	2.0	0		22	2-3	2.1	.35	
118. Digit V phalanges	no.	30	0-1	.6	.50		24	0-1	.6	.50	

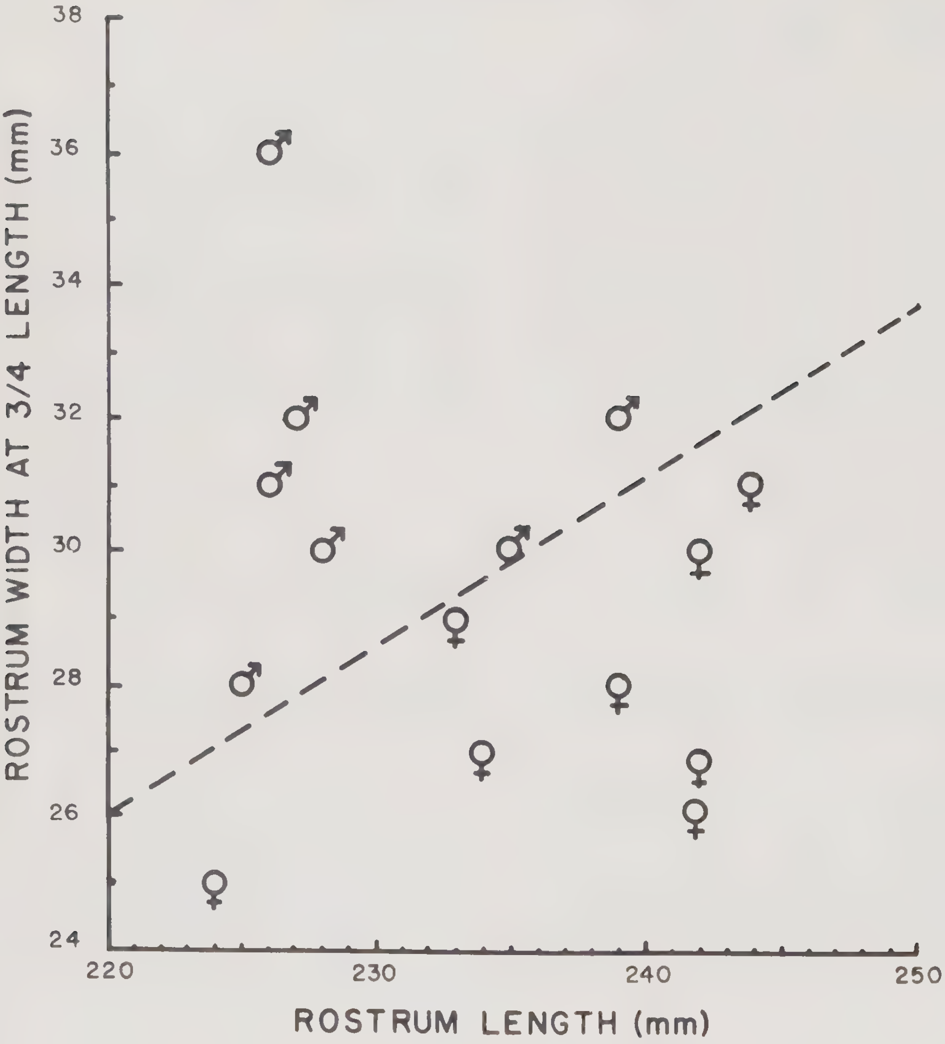

Figure 36. Sexual dimorphism of physically mature spotted porpoise in proportional width of rostrum at 3/4 length against rostrum length.

Although a significant component of variation in length of the occipitofrontal portion of the vertex confluence is ascribable to sexual dimorphism (see previous section), individual variation in length, as well as width, of this feature is considerable. Correlated with this feature is degree of exposure of the frontals and rudimentary interparietal. Development of the occipital overhang is not strongly correlated with development of musculature (James G. Mead, personal communication; based on detailed dissections) and shows great individual variation in addition to that owing to age. Width and height of the braincase show comparable variation. Length is least variable of the braincase measurements in absolute terms.

Feeding apparatus. The feeding apparatus is more variable than the braincase. The rostrum is more variable than the cranium in length, but not in width (by criterion of Lewontin's [1966] test, at $\alpha = 0.05$). Relation of rostral dimensions to parietal width did not in any case significantly decrease variation and some cases increased it, indicating that the rostrum and braincase vary to some degree independently.

Although a significant proportion of variation in rostrum size and shape results from sexual dimorphism and age (see previous section), individual variation among adults of the same sex and similar age is striking and can probably best be expressed by the coefficients of variation (5.91 for Set 2 and 4.71 for Set 6) of the ratio of rostrum length to basal width. The ratio ranges from 2.58 to 3.21 in Set 2 ($N = 22, \bar{x} = 2.81, s = 1.66$) and from 2.49 to 3.06 in Set 6 ($N = 19, \bar{x} = 2.87, s = 0.135$). The mandible varies in the same way.

The premaxillaries are subject to considerable variation in the amount of dorsal contact; in some individuals these bones are completely separated for the full length of the rostrum. A similar situation obtains ventrally with respect to the contact of the maxillaries, although in all specimens examined the maxillaries are in contact at least at the level of the end of the tooth row. The exposure of the vomer varies similarly (fig. 37).

The premaxillaries are usually roughened dorsally where they meet the rough, less dense maxillaries. The extent of this encroachment varies considerably; in some specimens the premaxillaries are roughened laterally only in the distal third of the rostrum.

The range in tooth counts is 9 (37-45) and 10 (36-45) for upper and lower jaws respectively, in Set 6. On the average there is one more tooth in the upper than in the lower row. The foremost pair of mandibular teeth is often completely buried and can be detected only by probing or by grinding the bone. In specimens with high tooth counts and/or relatively short snouts, the hindmost teeth in both the mandibular and maxillary rows may become atypically crowded and/or reduced in size (fig. 37).

The size of the posttemporal fossa (measurement nos. 19, 20, 21, and 22) varies considerably among animals of the same sex and similar age; least variable among the absolute measures in both single-school samples is the major diameter of the opening through which the temporal muscle passes (no. 21). Degree of definition of the posttemporal fossa also varies markedly, from specimens in which the boundary is scarcely discernible or intermittent to those in which it is a complete strongly developed flange. Degree of development of this feature is correlated with degree of development of the highly variable occipital overhang (fig. 24).

The hyals are extremely variable in both size and shape. The body of the basihyal may be nearly rectangular or trapezoidal. Its posterior process varies markedly in width and may be entire or bifurcate. The thyrohyals vary widely in shape and in the angle of attachment to the basihyal. Degree of fusion of the hyals, although determined in part by age (see section on development), varies within series of specimens of similar age, including physically mature animals. The length of the thyrohyal, although also in part age-determined, varies within series of specimens of similar age, including physically mature animals. The stylohyals also vary widely, in length and robustness.

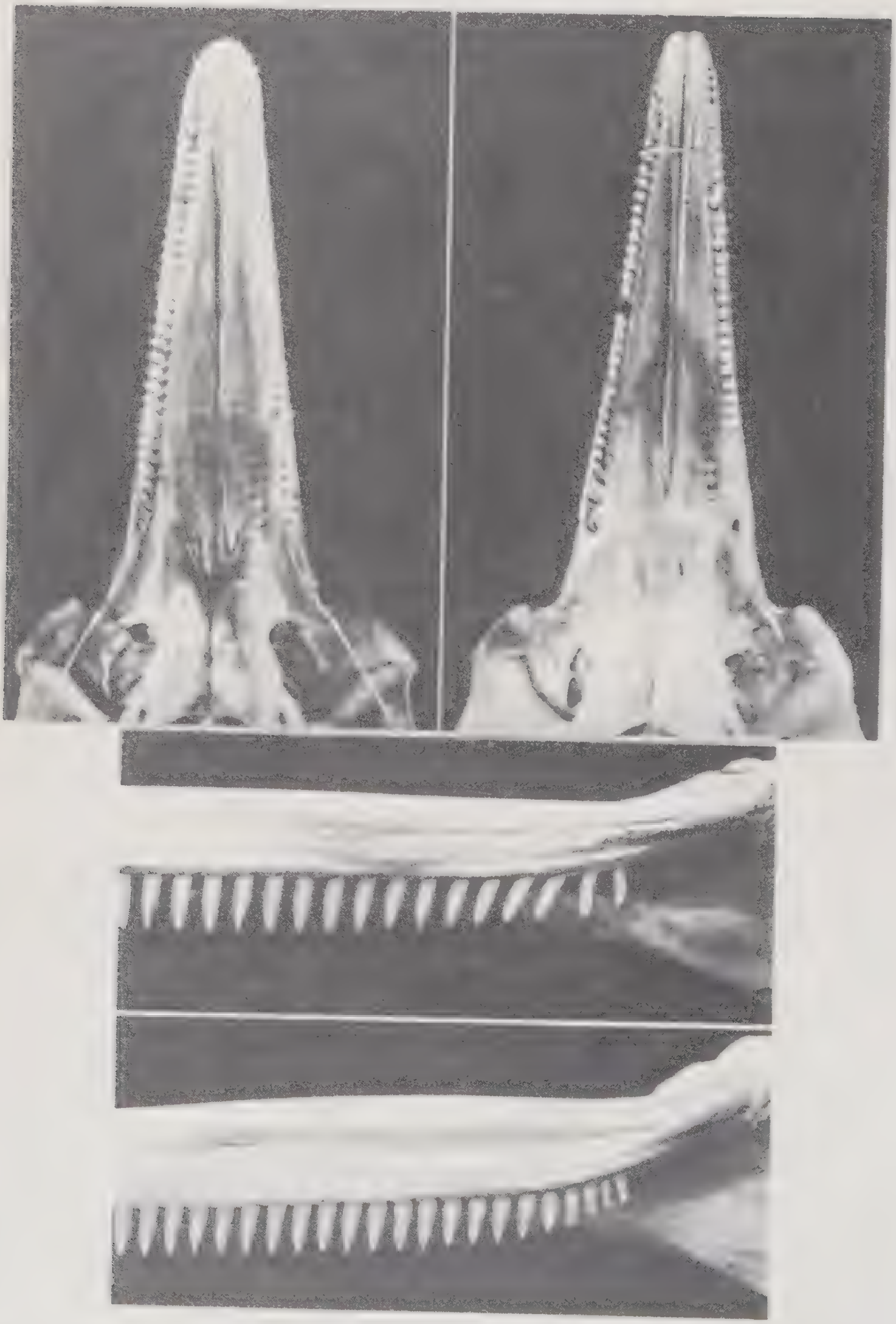

Figure 37. Individual variation in elements of the feeding apparatus of the skull of adult spotted porpoise: ventral view of rostra with no exposure of vomer (top left) and (top right) vomer exposed, (bottom) variation in spacing and size of posterior teeth in upper tooth row.

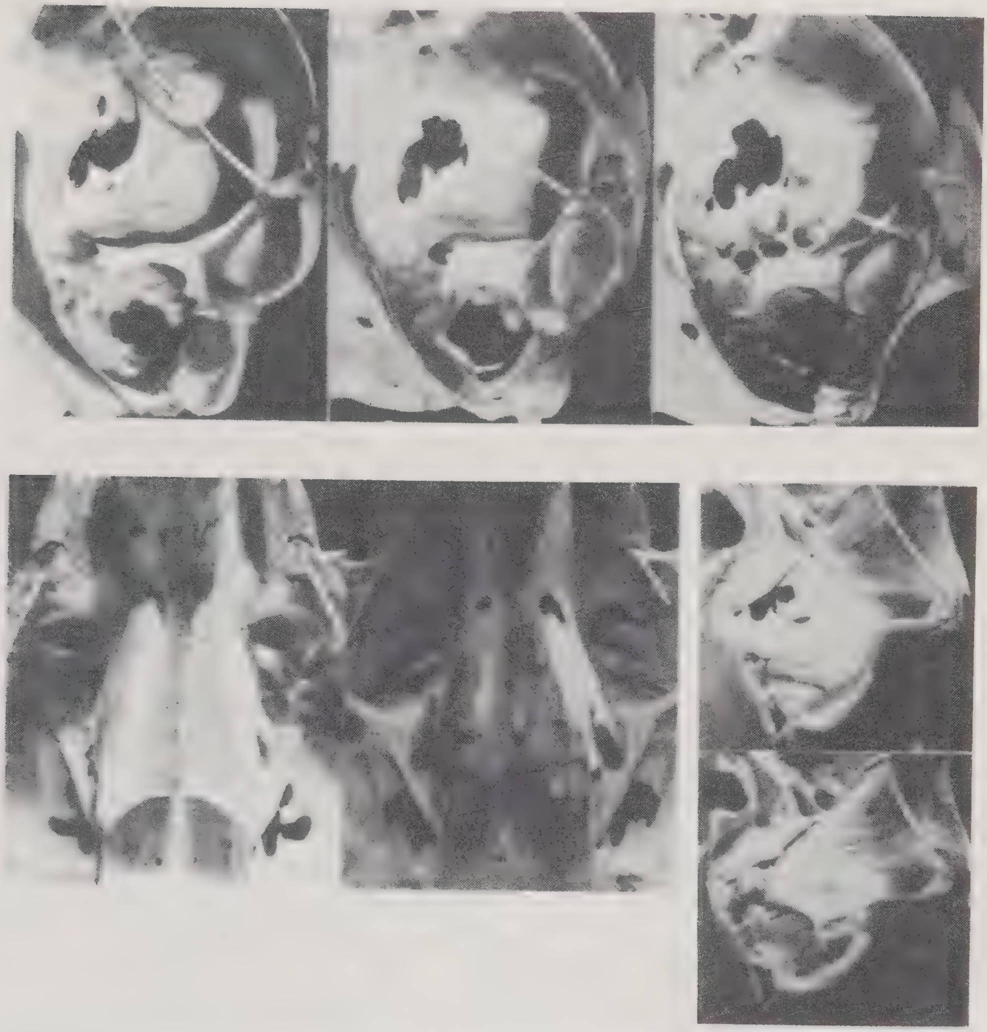

Figure 38. Individual variation of skull of adult spotted porpoise in ventral aspect: (top) variation in shape of falciform process; (bottom right) presence and absence of segmented squamosal-alisphenoid bar above falciform process; (bottom left) variation in shape and mesial separation of pterygoids.

Vision apparatus. In most individuals the orbit is rounded in outline, but in some, dorsal flattening creates a slight rectangularity. Also, in some specimens, the outline of the orbit is distorted by greater than usual posterior extension of the lacrimal.

Hearing apparatus. The lengths of the tympanoperiotics (nos. 30 and 31 in table 10) have relatively low coefficients of variation, especially in the sample for Set 2. Most variation in length of the bulla is owing to varying extension of the thin anteroventral lip of the tympanic tube. In some individuals, however, the bones are noticeably smaller or larger than usual. There is also considerable variation in the shape of the other end of the bulla, and the margin of the "mastoid process" (actually composed of extensions of the mastoid and squamosal) is quite variable in size, outline, and degree of compactness. Features more intimately involved in the physical processes of hearing, however, such as the promontorium, the sigmoid processes, and the posterior conical process, are more constant in size and shape, even among tympanoperiotics of disparate overall size.

In ventral view of the skull, the falciform process of the squamosal varies greatly in length, robustness, and distal elaboration (fig. 38, top). In some individuals, the elaboration extends anterodorsad to form a three-dimensional basketwork of delicate bones in contact with the alisphenoid. Mesial definition of the tympanosquamosal recess varies from complete absence to a depression bounded by an excavated flange 2 or 3 mm high. The foramen ovale may be essentially flush or may be surrounded by an elevated infundibulum of varying height. In some individuals the foramen is partly closed by osteosclerotic invasion. Three of 40 specimens examined exhibit a discrete mandibular foramen, adjacent and anteromesial to the formen ovale. In some individuals the foramen ovale is lost in a larger hiatus in the alisphenoid. The lateral bar of bone, just dorsal to the falciform process, formed by mesial extension of the squamosal and ventral development of the alisphenoid and perhaps serving a structural reinforcing function, varies remarkably in its degree of development: in some specimens it is so weakly expressed as to be essentially absent; and in others, it is a massive structure bearing an obvious transverse suture (fig. 38, middle). Weak development of this structure appears to be compensated for by increased anterior thickening of the alisphenoid.

Aspects of the base of the skull that delimit the peribullary space, namely, form and size of the basoccipital crests and excavation of the paroccipital processes, are rather more constant in their expression than are the features discussed above, although in some specimens the ventral margins of the crests are less entire than in most.

The tips of the pterygoid hamuli may diverge at an acute angle or form only a gentle curve posteriorly (fig. 38, bottom). The pterygoids may be in contact mesially or may be separated by as much as 8 mm. Fenestration is variable, being completely absent in some specimens and extensive in others.

The lateral wing of the palatine is extremely variable in expression. In lateral view, it may stop short of the dorsally-directed notch in the mesial lamina or extend posteriad to nearly touch the sphenoid wing. In some it is nearly absent, and in others extends posterolaterely around the posterior margin of the palatine, to form a horizontal shelf or bridge below the antorbital fossa. Such extension is correlated with the elaboration of the falciform process described above. The deep fossa formed at the juncture of the mesial lamina and the sphenoid wing varies considerably in depth and definition.

The configuration of the antorbital fossa varies markedly, from a small rather well-defined ovate or pyriform aperture, to a large open area (fig. 39).

Breathing and sound-producing apparatus. The prenarial triangle in most individuals is concave but in some is flat and nearly level with the denser lateral portions of the premaxillae. The triangle may be essentially featureless or may be very rugose and scored with transverse furrows. There is little variation in the overall conformation of the prenarial shield, although in some individuals the usual pronounced hump on the lateral margin of the right premaxillary is all but absent. In some specimens the posterior extremity of the right premaxillary stops short of the nasal, in others it extends beyond it for as much as a centimeter.

The ossified portion of the mesethmoidal shield varies dorsally from being truncated short of the nasals to being a broad triangle nearly covering the anterior aspect of the nasals. The nasals, and the vertex of which they are the major component, vary greatly in height and width. The right nasal may be incompletely bipartite.

The degree to which the maxillaries overlay the frontals varies from nearly complete coverage, leaving only a small (~ 2 cm square) area of the frontal exposed behind the nasal, to a state in which the frontals are exposed for their full width.

The antorbital notch varies in depth from 0 mm to approximately 6 mm and also shows considerably variation in form (fig. 39).

Summary. Some feeling for the relative variability of the functional units of the cranium can be had by examination of figure 40, in which coefficients of variation for cranial measurements are presented in an analog fashion and separated into groups according to which functional unit supposedly has greatest influence on absolute size of the measurements. Excluded are measurements that are extremely variable, including projection of premaxillaries (no. 23), nasals to crest (no. 24), and occipital overhang (no. 29); those for which it would appear that size is not most influenced by the functional unit to which they belong primarily; and those for which the functional relationship is unclear, including zygomatic width (no. 14), pterygoid length (no. 28), and length of mandibular fossa (no. 40). It appears that the feeding apparatus is the most variable, closely followed by the breathing and sound-producing apparatus, and that the braincase, hearing, and vision apparatuses are significantly less variable.

The series of "adult" skulls impressed me with the correlation of functionally seemingly unrelated structures in contribution to overall shape. Some skulls seem very long, in every respect; others seem very short, again with many features contributing to the impression. The aspect of individual variation can be examined from the synthetic standpoint of determining general factors, as opposed to the reductionist standpoint of considering more-or-less independent variances associated with functional systems. General factors can be examined with principal components analysis, which is a method for summarizing simultaneous variation of a large number of variables in terms of a few major "factors" (see Methods above). This analysis was performed on 25 cranial measurements of 37 of the specimens from Sets 2 and 6.

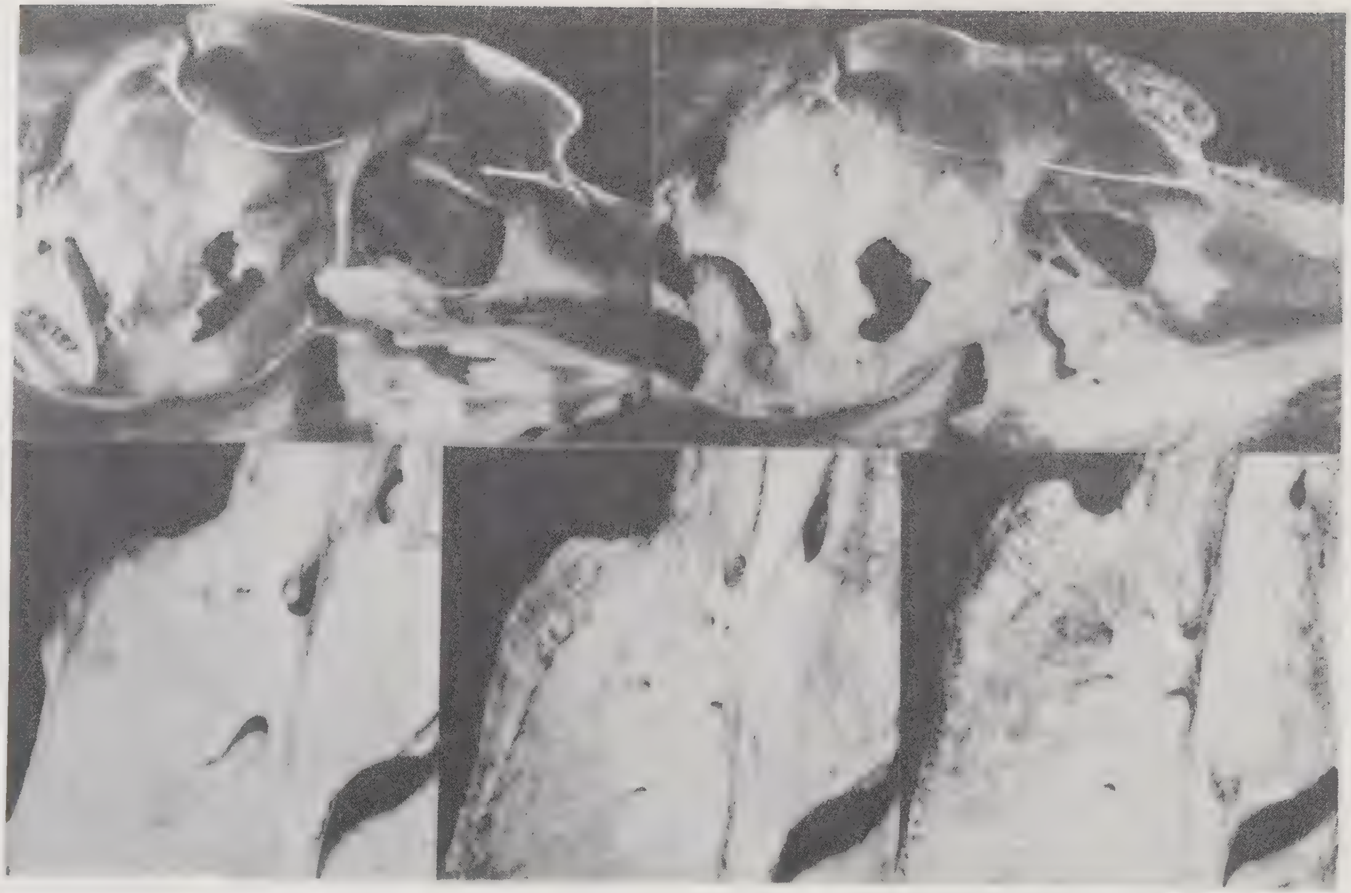

Figure 39. Individual variation in skull of adult spotted porpoise in (top) size of antorbital fossa, and (bottom) development of antorbital notch.

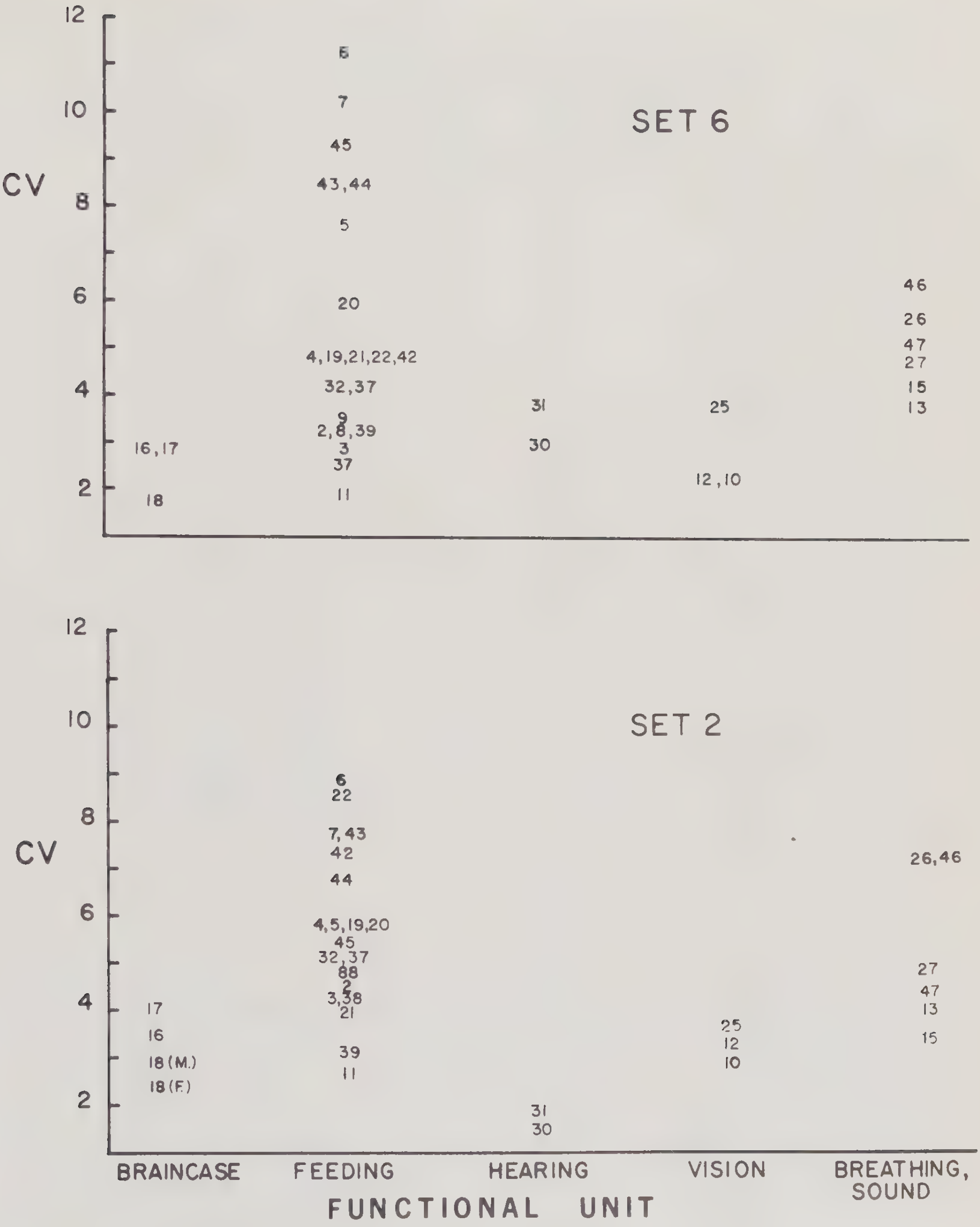

Figure 40. Comparative individual variation of functional units of skull of adult spotted porpoise in two single-school samples. Numbers refer to measurements listed in table 12 and illustrated in figure 2. Coefficients of variability on vertical axis.

Table 11. First principal component in principal components analysis of skull measurements of spotted porpoise.

Specimen field number	Score	Sex	Maturity ++physical +sexual	Dentinal layers	Condylobasal length (mm)	
CV 287	0.709	M		6.0	400	
CV261	0.694	F		5.0	411	
CV293	0.595	M	+	8.0	406	
CV313	0.550	M		5.0	408	58% males
CV265	0.534	M	++	9.0	399	Average 8.2 layers
CV268	0.507	F	++	(–)	404	Average condylobasal
CV 279	0.491	M	++	(–)	401	length = 400 mm
CV 289	0.405	M		8.5	398	
CV 270	0.354	F	++	12.0	396	
CV 319	0.344	F		8.0	394	
CV 280	0.311	M	++	8.0	384	
CV 291	0.263	F	++	12.5	393	
CV 281	0.237	F		6.0	397	
CV 282	0.152	F		8.0	391	
CV 309	0.133	F	++	8.5	390	
CV 273	0.124	F		(–)	391	42% males
CV 277	0.115	F	+	(–)	397	Average 8.1 layers
CV 292	0.075	M	++	12.5	388	Average condylobasal
CV 274	0.020	M		6.0	388	length = 391 mm
CV 259	–0.005	M		7.5	394	
CV 278	–0.015	M		(–)	398	
CV 271	–0.040	F	+	7.0	381	
CV 263	–0.067	M		6.0	388	
CV 272	–0.103	F	++	11.0	391	
CV 316	–0.156	M		9.0	380	
CV 269	–0.175	F	+	7.0	385	
CV 264	–0.186	M		6.0	385	
CV 320	–0.205	M		7.5	388	69% males
CV 275	–0.224	M		7.0	382	Average 7.7 layers
CV 290	–0.242	F		5.5	385	Average condylobasal
CV 276	–0.271	M		6.0	382	length = 377 mm
CV 311	–0.345	M	++	11.0	384	
CV 315	–0.480	M		7.5	371	
CV 260	–0.748	F	+	8.0	369	
CV 267	–0.835	M	+	9.5	369	
CV 310	–1.038	M	+	(–)	360	
CV 312	–1.481	F		8.0	356	

Table 12. Second principal component in principal components analysis of skull measurements of spotted porpoise.

Specimen field number	Score	Sex	Maturity ++physical +sexual	Dentinal layers	Zygomatic width (mm)	
CV 280	1.337	M	++	8.0	174	
CV 292	0.647	M	++	12.5	167	
CV 287	0.507	M		10.0	174	
CV 260	0.439	F	+	8.0	164	83% males
CV 265	0.411	M	++	9.0	168	Average 9.1 layers
CV 275	0.381	M		7.0	161	Average zygomatic
CV 267	0.262	M	+	9.5	159	width = 165 mm
CV 279	0.254	M	++	(–)	167	
CV 270	0.228	F	++	12.0	165	
CV 316	0.206	M		9.0	162	
CV 310	0.154	M	+	(–)	161	
CV 276	0.124	M		6.0	158	
CV 271	0.117	F	+	7.0	162	
CV 272	0.107	F	++	11.0	161	
CV 311	0.099	M	++	10.0	163	
CV 293	0.074	M	+	8.0	165	67% males
CV 309	0.001	F	++	8.5	166	Average 7.8 layers
CV 289	–0.018	M		8.5	164	Average zygomatic
CV 273	–0.019	F		(–)	164	width = 163 mm
CV 315	–0.025	M		7.5	158	
CV 319	–0.047	F		8.0	164	
CV 274	–0.067	M		6.0	163	
CV 290	–0.134	F		5.5	160	
CV 264	–0.157	M		6.0	163	
CV 320	–0.173	M		7.5	159	
CV 263	–0.173	M		6.0	161	
CV 291	–0.180	F	++	12.5	160	
CV 281	–0.288	F		6.0	164	38% males
CV 282	–0.298	F		8.0	162	Average 7.3 layers
CV 278	–0.320	M		(–)	158	Average zygomatic
CV 268	–0.345	F	++	(–)	162	width = 160 mm
CV 269	–0.365	F	+	7.0	160	
CV 259	–0.381	M		7.5	163	
CV 312	–0.414	F		8.0	153	
CV 261	–0.522	F		5.0	162	
CV 313	–0.693	M		5.0	157	
CV 277	–0.712	F	+	(–)	160	

In evaluation of the results of principal components analysis, the first component is generally taken to represent size and the second, shape (Jolicoeur and Mosimann, 1960; Cooley and Lohnes, 1962; Seal, 1964). Interpretation of components beyond the second is usually not attempted, because of uncertainty as to exactly what they represent in geometrically meaningful terms and because of the small size of each in terms of percentage of total variance.

The 37 specimens can be ranked by score for each of the first two principal axes (tables 11 and 12), which account for 33% and 22% of the variance. Included for each specimen are sex, degree of maturity, number of postnatal dentinal layers, and value for the measurement that contributes most to the component in question. The absolute values of the products of loading coefficients (eigenvectors) and means of the measurement (grand mean of specimens in tables 11 and 12) are used as an index of relative determining power of the measurements. For each component, these data are summarized over each of three arbitrary subsample increments to facilitate examination of trends within the ranked order.

The largest component of the variance (33%) of the series, to which condylobasal length is the best index, is associated with individual variation in size and is not significantly associated with developmental or sexually derived variation. Comparison of two skulls (fig. 41, left) from opposite parts of the ranked order for the first axis (but with comparable positions along the second axis) demonstrates association of the variance with scale rather than proportion.

The second component (22%) is apparently another matter entirely. It is primarily associated with a proportional width factor (zygomatic width is the greatest contributor), and score is strongly influenced by sex and age in combination. Older and/or male skulls tend to be proportionately broader than younger and/or female skulls. Condylobasal length is a negative contributor to the score, reflecting the above-discussed longer snout length of old females. Again, comparison of skulls from opposite ends of the ranked order (fig. 41, right) demonstrates the nature of the variation encompassed by this particular component of the total variance.

Postcranial skeleton

Axial postcranial skeleton. It is most appropriate to consider meristic variation in the vertebral column in terms of absolute variation, as indicated by range and standard deviation. From this standpoint, the thoracic series (no. 48), together with the vertebral ribs (nos. 78 and 79), two-headed ribs (nos 80 and 81), sternal ribs (nos. 84 and 85), and floating ribs (nos. 82 and 83), is least variable, with range 2-4 and standard deviation less than 0.8. The lumbar and caudal series, with associated meristic characters, are about equally variable, with range 5-8 and standard deviation 1-2. Total vertebral count has a range of only 5 (nos. 79-83) in both samples, indicating some degree of compensation between the series. Similarly, absolute variation in total number of hemopophyses is about equal to variation in location of first and last hemopophyses.

The atlas varies sharply in ventral outline of the cranial articulating surface, size and angle of projection of the transverse processes, length and robustness of the neural spine, and degree of development of the accessory spine on each side of the dorsal edge of the

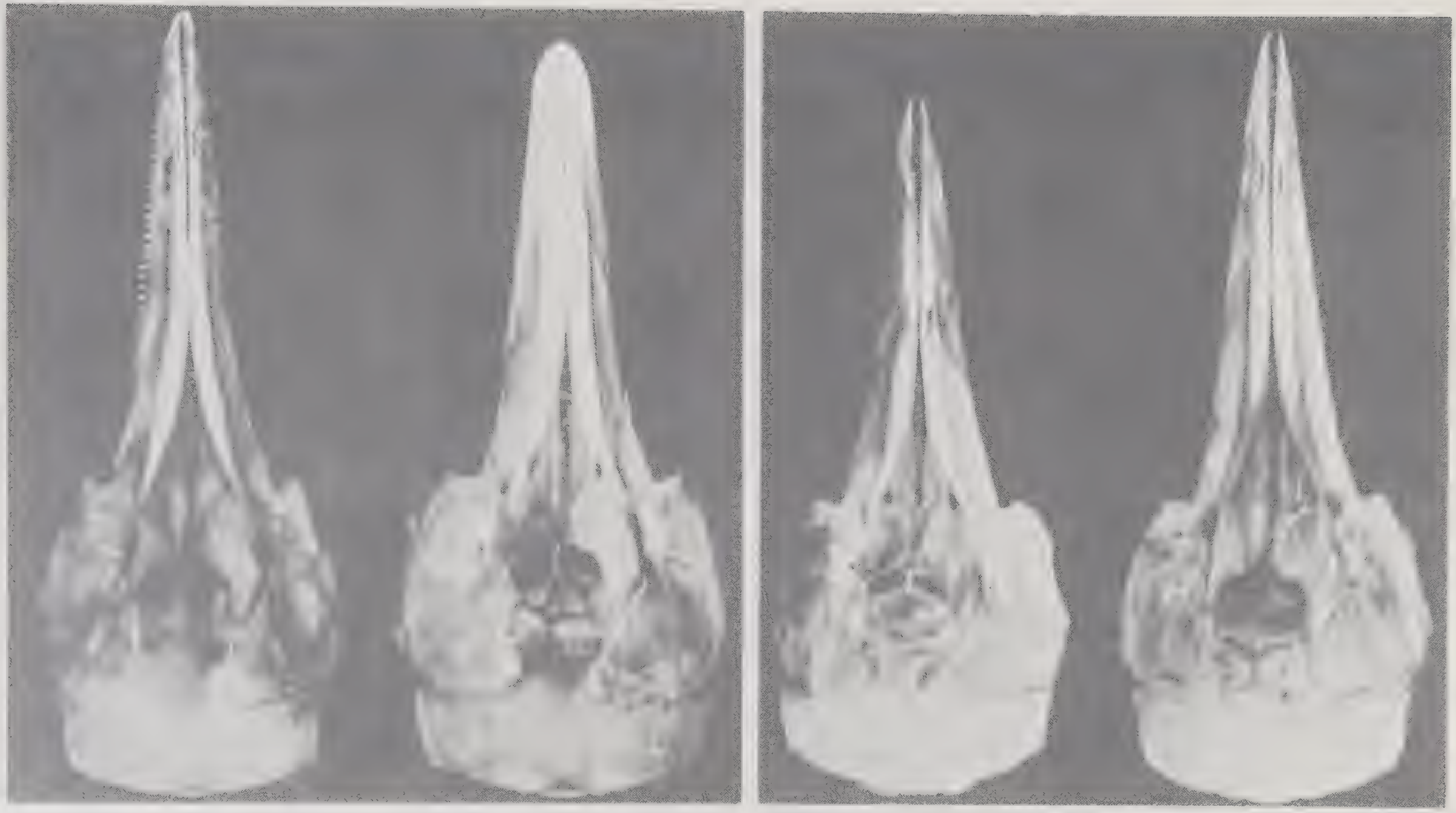

Figure 41. Individual variation of crania of adult spotted porpoise, along principal component axes representing general size and width factors: (right to left) CV 291 (USNM no. 395596), adult female, 12.5 layers and CV 312 (USNM no. 395466), adult female, 8 layers, divergent on axis 1 (size), but nearly coequal on axis 2 (width); CV 280 (USNM no. 395391), male, 8 layers, and CV 277 (USNM no. 395388), adult female, at extremes on axis 2 but co-equal on axis 1.

cranial articulating surface. The accessory spine may form something resembling a neural arch. The coefficients of variation indicate that the variability of the atlas in its height (no. 54) and in the width of its cranial articulating surface (no. 53) is significantly lower than for the apophyses (nos. 55 and 56).

Development of the ventral keel and accessory spine of the axis is correlated with development of the neural spine of the atlas, in some specimens both being very weakly developed. In some specimens they extend posteriad to articulate with a facet on the third vertebra. Development of the lateral processes of the axis does not appear to be correlated with that of the lateral processes of the atlas. The axis is firmly fused to the atlas except for a portion of the neural arch on each side. In some individuals the third cervical is similarly fused to the axis, and fusion may occur between other elements of the series in varying combination. The number of cervicals bearing incomplete arches is variable. One of the six physically mature specimens from Set 2 and two from Set 6 each have one cervical with an incomplete arch. In some individuals one side of the incomplete arch may even develop a long neural spine. Development of the ventrolateral processes on the fith and sixth cervicals also exhibits great individual variation. In some specimens, greatest development is on the seventh vertebra.

Development of the neural spine of the first thoracic vertebra varies widely among individuals, as does thickness of the centrum. In one subadult the arches of the last cervical and the first thoracic are incomplete, and the left side of the arch of the thoracic is fused to the right side of the arch of the cervical. The second thoracic is the first bearing a neural spine. The vertebral count (83) for this specimen is at the extreme upper end of the range for all specimens examined. Variability of the length of the neural spines decreases posteriad along the thoracic series (nos. 69, 70, 71, and 72). A similar posteriorly increasing stability is apparent in the transverse processes (nos. 74 and 76).

In the caudal series, variation is most obvious in the size, shape, and fusion of the hemopophyses, or chevron bones. The first five chevron bones, comprising of ten elements, may be fused in almost any combination, with differences between right and left sides. The first arch is most variable in size (no. 100), the last (no. 102) is next most variable. The length of the longest arch (no. 101), usually tenth or eleventh in the series, is most stable. Considerable variation is present in the terminus of the vertebral column, in the taper and in the size of the last vertebra. In some specimens the last two vertebrae are fused.

The vertebral ribs vary in length, robustness, and curvature. In some specimens, the capitulum is extremely short and slender. Pronounced uncinate processes exist on the first vertebral ribs of some specimens.

The number of two-headed ribs may vary between sides of a single specimen. Often, one member of the last pair in a series of elements is more developed than the other. When this is true for one series, it usually holds for other series in the same skeleton. For example, if the last left vertebral rib is longer than the right, then the last left sternal rib is longer, the last left two-headed rib shows greater development of the capitulum, and so on. The floating ribs may be absent.

The sternal ribs vary in length, robustness, and curvature along with the vertebral ribs. In some specimens the first sternal rib on one side bifurcates distally and articulates with the manubrium in two places. The anterior prong of the bifurcation may be a separate bone. The sternum is extremely variable in every respect (fig. 42). The manubrium may

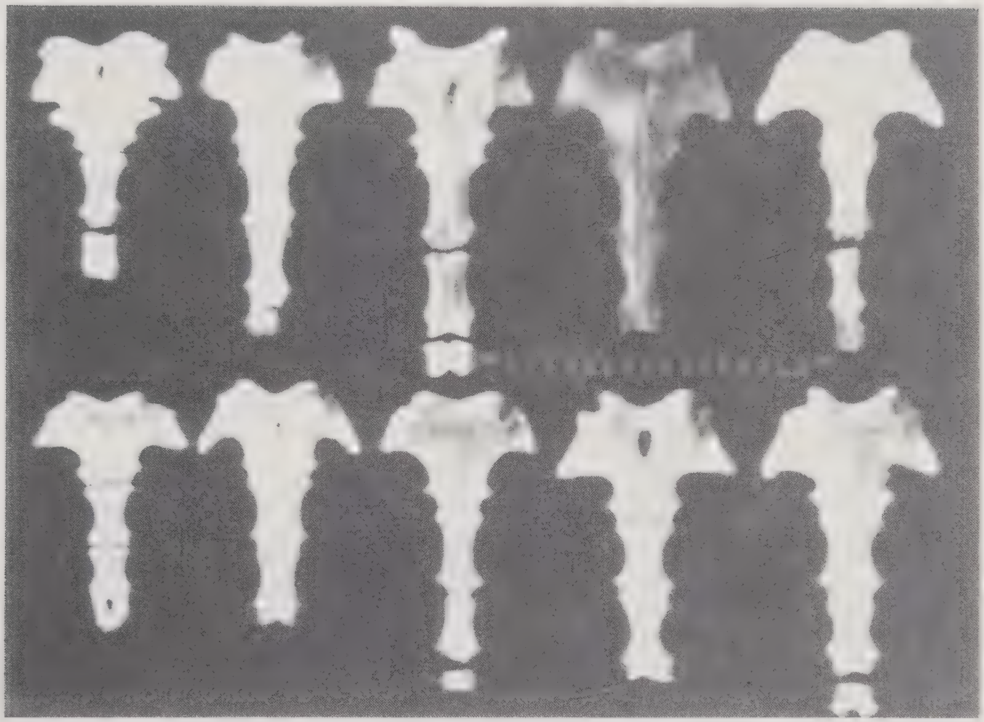

Figure 42. Individual variation in sternum of physically mature spotted porpoise. Top and bottom rows are each from a single school.

be perforate or nonperforate; it may have one lateral process on each side, or two; it may be asymmetrical; and it varies greatly in massiveness and overall contour. There may be two or three mesosternal elements. Each may be comparatively short and robust or long and slender. The last mesosternal may be a well-developed element or a very small ossification, and may be entire, bipartite, or perforate. The pattern of fusion varies among physically mature specimens.

Anterior appendicular skeleton. Among the measurements of the scapula (nos. 103-107), widths of the coracoid and metacromion processes show greatest variability. Also quite variable are the shape of the metacromion process, the outline of the coracovertebral border, and the topography of the infraspinal fossa. In some specimens the supraspinal fossa opens anteriorly, in others laterally.

The proximal forelimb (nos. 108-112) is about as variable as the scapula and the posteriormost elements of the axial skeleton, much less so than the middle and posterior vertebral column, the ribs, and the sternum, although the radius and ulna of some specimens are noticeably longer and slenderer than those of others. The carpal series varies in number and precise relationships of elements. The trapezium may be absent. The lunar and unciform may be fused. The trapezoid is rarely present. One metacarpal is consistently present on each digit. Variation in phalangical counts is described in the section on development.

Posterior appendicular skeleton. The extreme variation in size and form of the pelvic rudiment is illustrated above in the section on development. Nothing approaching the complex appendicular structure, reported by Lönnberg (1938) for a large male from the type locality of *S. graffmani,* consisting of pelvic and femoral rudiments on one side and separate rudiments of ischium, ileum, and femur on the other, was encountered in any of the skeletons examined. All rudiments examined consist of a single rodlike bone with variable distal development.

Comparison with variation in other species

The nature and range of variation discussed above for samples that are probably from single populations are not surprising in veiw of the patterns of variation in other, terrestrial mammals. Allen in 1894 documented similar variation in a population of *Neotoma.* This paper contains a statement hauntingly reminiscent of True's (1889) above-quoted complaint of puzzlement over cranial variation in *Stenella.* Allen said, "Thus in a series of fifty skulls of *Neotoma micropus* it would be easy to select extremes, of even individual variation, that depart so widely from the average, in one or more characters, as to deceive even an expert, on considering these alone, into the belief that they must represent very distinct species; yet in the present instance the proof that such is not the case is overwhelming."

The results also closely parallel those obtained in the very few previously accomplished studies of individual variation in the Delphinidae (sensu lato). Yamada (1956) examined skeletal material of 124 of approximately 150 false killer whales, *Pseudorca crassidens* (Owen), that stranded over a 30-mile stretch of coast in the Dornoch Firth, Scotland, in October 1927. He did not include sample sizes, data, or statistics in his paper, but stated with respect to the skull that "the breadth of braincase varies little, except that broader dimensions occur in greater skulls." He found, however, that the tip of the rostrum varies considerably in form, "from pointed and tapering ends through round ones to stumps." These findings concerning relative variability of the braincase and elements of the feeding apparatus coincide well with the pattern in the spotted porpoise. Yamada also stated that "some [of the skulls] are very slender, some are stout and very broad, but the indices between either transverse or longitudinal dimensions usually show very high linear correlation, whereas others are less correlated," a result indicating a situation parallel to that in the spotted porpoise where general length and width factors (principal axes of variation) can be defined. Yamada's findings with respect to meristic epigenetic variation in the postcranial skeleton also closely followed the patterns defined here for the spotted porpoise.

Cadenat (1959) published data for several series of *Delphinus delphis* L. captured at various localities on the west coast of Africa. In 57 specimens, he found tooth counts to range from 41 to 55. The greatest range in a single sample was 41-48 in 14 specimens captured together on the coast of Senegal. These ranges are similar to those encountered in the spotted porpoise.

Kleinenberg (1956) published extensive data including osteological measurements, on *Tursiops, Delphinus,* and *Phocoena* in the Black Sea, but unfortunately no indication of degree of maturity of the individual specimens is included, making difficult the isolation of individual variation.

Fraser (1966) examined a large series, from Saint Helena Island in the South Atlantic, of *Stenella* cf. *capensis,* a form closely related to if not conspecific with the spotted porpoise of the eastern Pacific. On the basis of the uniformity of the sample, he inferred that the Saint Helena population is an isolated interbreeding unit. He published averages, ranges, standard deviations, and coefficients of variability for condylobasal length and 13 other measurements expressed as percentage of condylobasal length for 39 adult skulls. Data on sex of the specimens were not available. Comparison of the coefficients of variability with the coefficients for the characters found to be nondimorphic in the spotted porpoise (table 5) show constancy of proportion similar to that in the two single-set series of spotted porpoise. Three of the coefficients for 11 comparable measurements in the Saint Helena series were greater than for both eastern Pacific series, five were lesser than for both, and three were intermediate between the two series.

The several forms thus far studied agree closely in the nature and extent of individual variation. This indicates that the results reported here for large series of spotted porpoise probably apply generally to the Delphinidae and can be used as a basis for evaluation of the siginificance of variation encountered within or between smaller samples of species of *Stenella,* or species of other delphinid genera.

Geographical Variation

I found pronounced geographical variation in the spotted porpoise in skeletal characters. Geographical variation has not previously been analyzed adequately for any form of *Stenella,* primarily because of the paucity of available material from known localities. Fraser (1950) examined skull variation in the spotted porpoise in great detail, but 15 of the 31 specimens available to him were from unknown localities (discussed above in Historical Review).

This analysis of geographical variation is based on 132 specimens from known localities in the eastern tropical Pacific and 15 from Hawaii. The area covered in the eastern Pacific (fig. 43) extends from Guaymas, Sonora, Mexico (27°56′N, 111°08′W) in the north to Gorgona Island, Colombia (~ 3°N, 78°20′W) in the south, and seaward to 135° W (approximately midway bewteen Clipperton Island and Hawaii). The only measurements not made by me are those published by Lönnberg (1934, 1938).

Skeletal specimens included in analysis of geographical variation

Coastal–1 from 13°15′N, 79°25′W (USNM 254671), 8 from ~7-9°N, 78°30′W (USNM 261427-34), 1 from ~3°N, 78°20′W (USNM 258641), 1 from ~27°56′N, 111° 08′W (CAS 12763), 1 from 21°52′N, 105°54′W (CAS 5581), 2 from 21°10′N, 106° 10′W (AMNH 80559 and CAS 5582), 1 from ~16°14′N, 98°29′W (AMNH 130216),

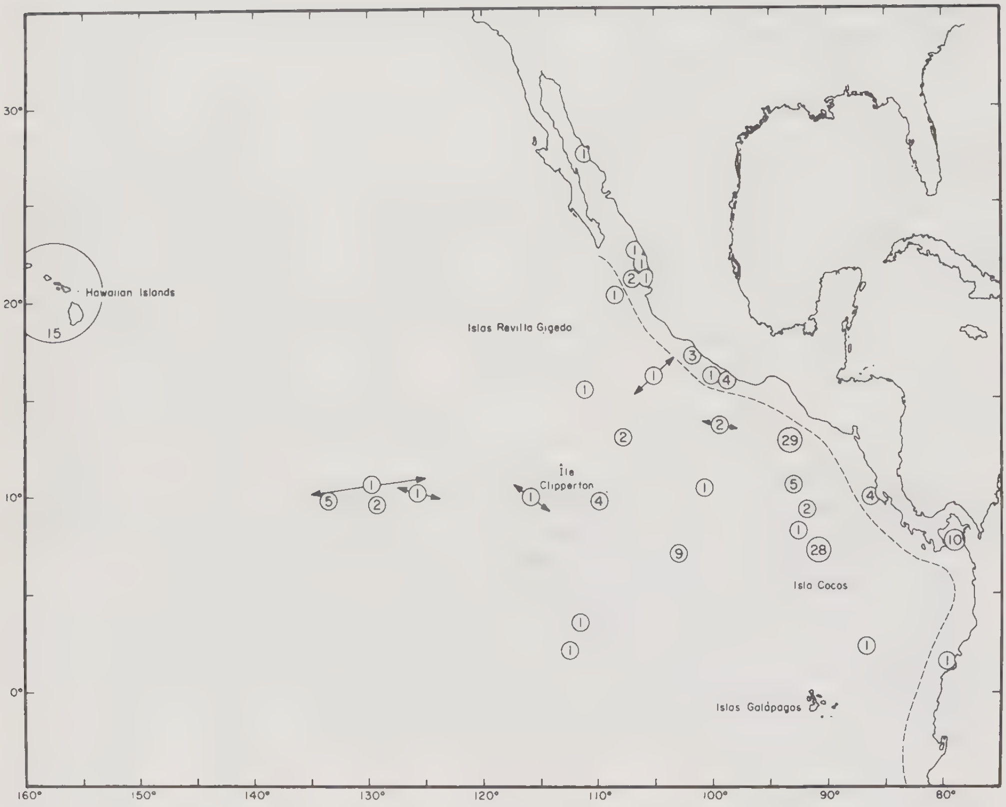

Figure 43. Provenance of specimens used in analysis of geographical variation of skeleton of spotted porpoise. Dashed line separates coastal and offshore forms.

3 from 17°32′N, 101°44′W (USNM 395926-8), 2 from 9°57′N, 85°56′W (USNM 395935-6), 1 from 9°50′N, 85°48′W (USNM 395937), 1 from 21°21′N, 105°31′W (MMBL 65-1), 1 from 22°58′N, 106°21′W (MMBL 66-3), 1 from 16°15′N, 98°55′W (USNM 395929), 1 from 9°53′N, 85°54′W (USNM 395938), 1 from 7°58′N, 82°02′W (USNM 259311), holotype of *Prodelphinus graffmani* Lönnberg, 1934, and 1 additional skeleton measured by Lönnberg from 16°58′N, 109° 55′W.

Offshore–33 from 12°51′N, 93°18′W (USNM 395276-7, 395330-4, 395336-9, 395395, 395397, 395417, 395458-9, 395461-2, 395464, 395467-8, 395528, 395530, 395594-5, 395597, 395603-6, 395608-9, 395611), 28 from 7°11′N, 90°32′W (USNM 395276-7, 395327-9, 395380, 395385, 395387-94, 395396, 395398, 395460, 395463, 395465-6, 395529, 395532, 395535, 395607, 395612-3, 395616), 5 from 10°31′N, 92°52′W (USNM 395207, 395264-6, 395268), 1 from 7°50′N, 90°32′W (SWFC - CV 160), 2 from 9°N, 92°W (SWFC - WP SG02), 1 from 9°50′-10°36′N, 89°47′-102°02′W (CAS 15663), 2 from 13°30′-14°06′N, 88°-100°56′W (MVZ 140640, CAS 15662), 1 from 14°20′N, 107°20′W (LACM - RLB 404), 2 from 12°08′N, 105°46′W (LACM - WAW 42 and 51), 1 from ~17°N, 100°45′W (LACM - WAW 55), 1 from 2°30′N, 86°W (USNM 396034), 2 from 9°28′N, 129°18′W (USNM 396027, 396175), 1 from 9°20′N, 110°44′W (USNM 396028), 1 from 11°N, 125°W or 10°-12°N, 135°-136°W (USNM 396029), 5 from 9°47′N, 133°25′W (USNM 396018-9, 396022, 396024-5), 2 from 8°10′N, 106°53′W (USNM 395407, SWFC - LGB 199), 1 from 7°47′N, 100°50′W (USNM 395410), 9 from 7°N, 103°W (SWFC - JSL 88-96), 1 from 14°55′N, 105°20′W-16°45′N, 103°04′W (LACM - GDF 48), 1 from 18°N, 107°W (SDMNH 21199), 1 from 9°-10°N, 114°-118°W (USNM 396038), 1 from 10°-11°N, 124°-128°W (USNM 396171), 1 from 8°N, 107°W (USNM 395408).

Hawaiian—8 from Hawaiian Islands (SWFC - WFP 92, USNM 112832-3, LACM 27069, LACM - NUHA, LACM - KAHILI, USNM 23290, MCZ 51701), 1 from Oahu (UBC 8511), and 6 from Penguin Banks, Molokai (USNM 395857-80).

AMNH = American Museum of Natural History, New York, N.Y., CAS = California Academy of Science, San Francisco, Calif., LACM = Los Angeles (Calif.) County Museum, MCZ = Museum of Comparative Zoology, Harvard University, Cambridge, Mass., MMBL = Marine Mammal Biological Laboratory, Sand Point NAS, Seattle, Wash., MVZ = Museum of Vertebrate Zoology, University of California, Berkely, SDMNH = San Diego (Calif.) Museum of Natural History, SWFC = Southwest Fisheries Center, La Jolla, Calif., UBC = University of British Columbia, Vancouver, USNM = U.S. National Museum, Washington, D.C.

The eastern Pacific skeletons fall into two groups, referred to below as the "coastal form" and the "offshore form." The 28 in the "coastal" group are from the Gulf of California, the coast of southern Mexico, the coast of Costa Rica, the Bay of Panama, and Gorgona Island, Colombia, and were all collected by harpooning or as beach pickups. The 19 "adult" skulls in this group range from 419 to 460 mm in condylobasal length, and the group includes the type specimen of *S. graffmani* (Lönnberg, 1934), for which the length of the mandible is known but not condylobasal length. The 104 "offshore" specimens were all collected in the tuna seine fishery in open, offshore waters; "adult" skulls (68) in this group range from 356 to 411 mm in condylobasal length. The most onshore specimen was captured "50 miles (80 km) west of Acapulco, Mexico," but tuna boat logbooks show that net sets are often made within 20-25 km off the coast on large schools of "spotters."

The smallest male skull, largest male skull, and a modal female skull (in CB length) are illustrated for the coastal and offshore groups (figs. 44-47). True (1906) published photos of two Hawaiian skulls; this form is not illustrated here.

Specimens in the two eastern Pacific groups are easily discriminated by eye on the basis of size; the coastal skulls are larger. The difference in size is not because of differential age makeup in the two samples; 6 of the 9 "juvenile" coastal skulls are longer than the longest "adult" offshore skull. The number of dentinal layers has not yet been examined for the coastal specimens, but the age structures of the two samples are similar, by the criterion of fusion of the premaxillary and maxillary bones. The differences between the two groups are most pronounced at the northern and southern ends of the range; the two largest coastal skulls are from Guaymas in the Gulf of California and from the Bay of Panama. The smallest is from the coast of Mexico between Manzanillo and Acapulco.

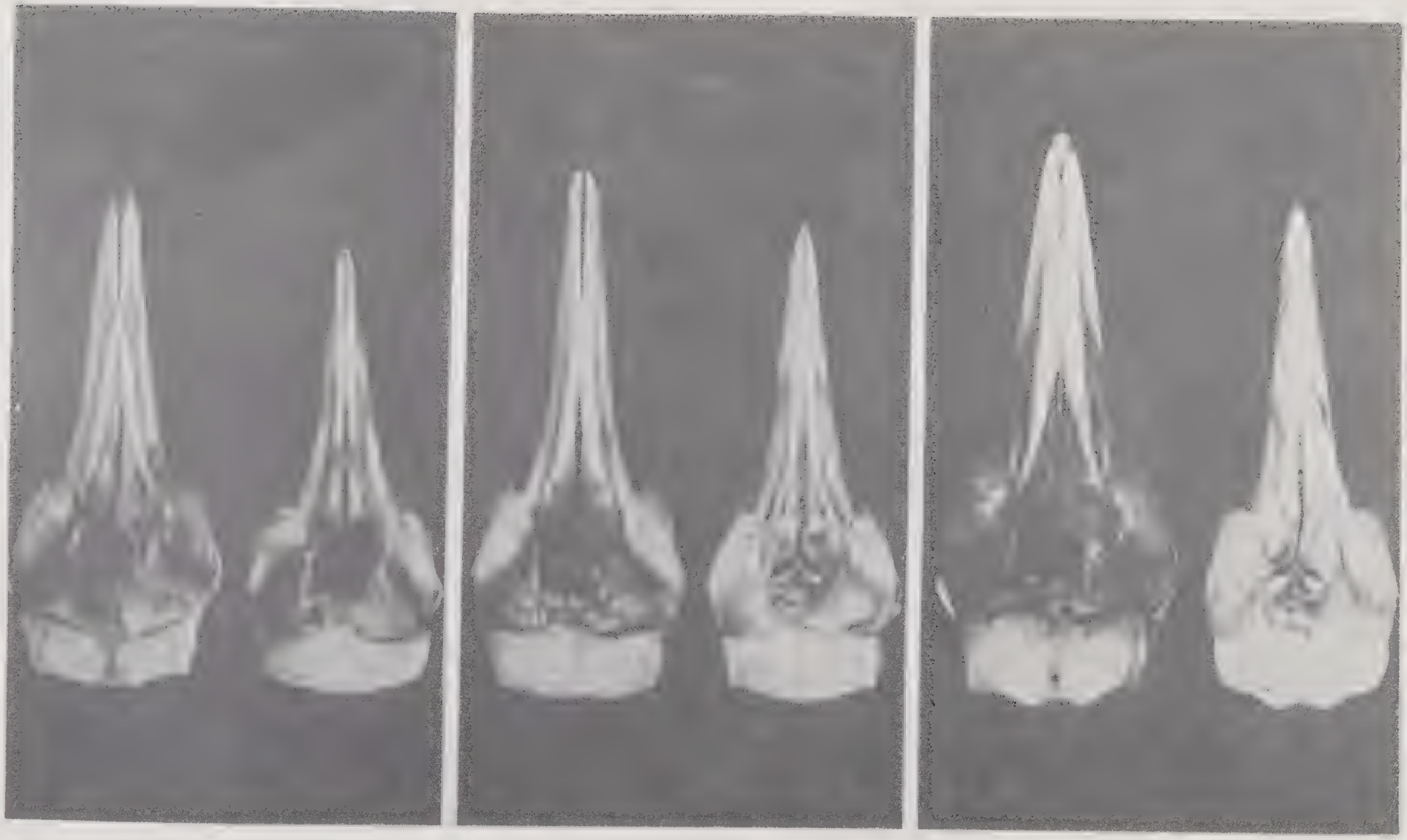

Figure 44. Geographical variation in skull of spotted porpoise: dorsal view of crania of shortest, modal and longest in coastal (left in each pair) and offshore (right) series. Coastal specimens are USNM No. 395928, MMBL No. 65-1 and USNM No. 261432 (skull is mislabeled in photo). Offshore specimens are USNM No. 395464, 395463 and 395467. Data are in table 13 (continued).

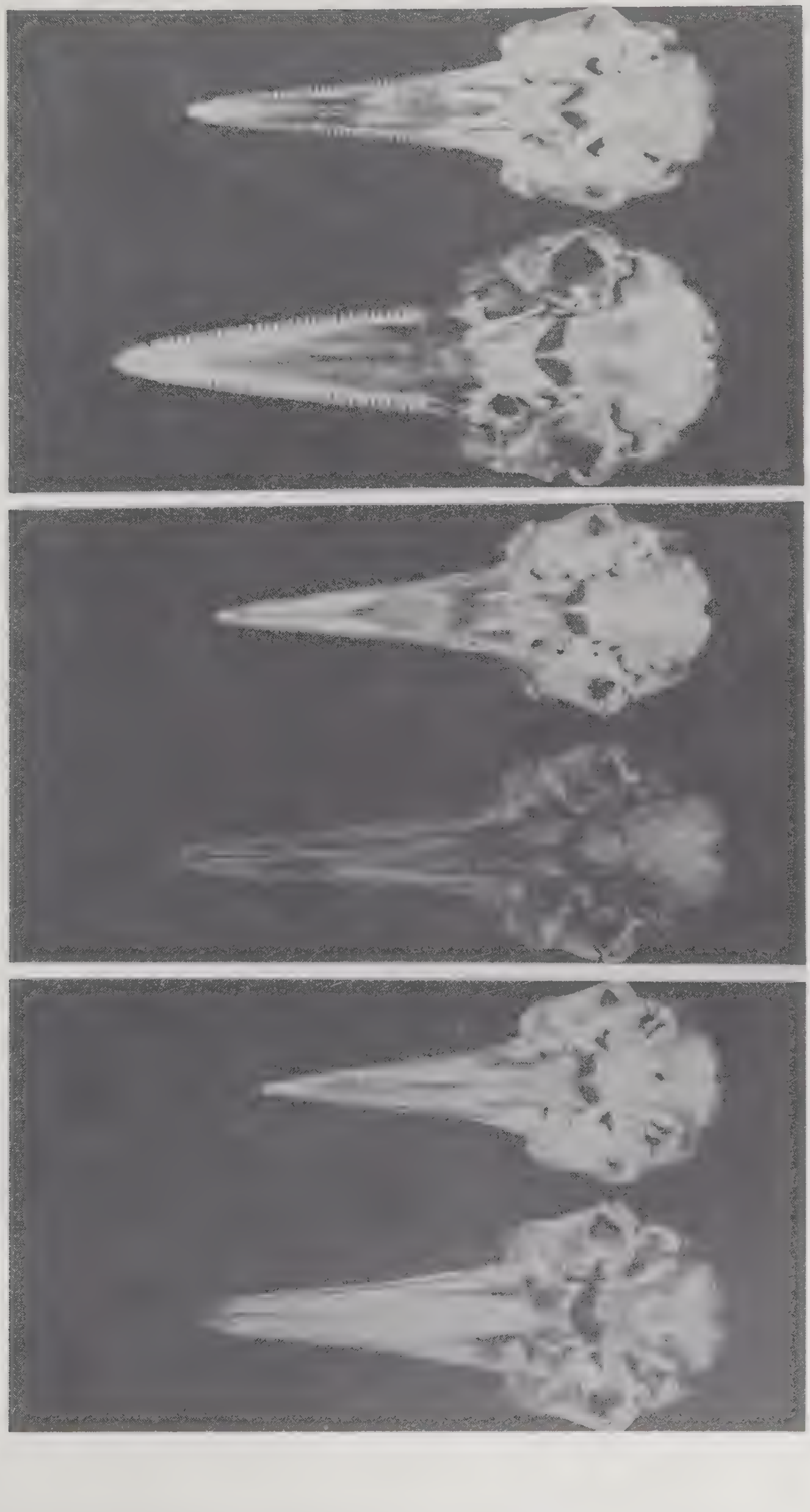

Figure 44 (continued). Geographical variation in skull of spotted porpoise: ventral view of crania of shortest, modal and longest in coastal (left in each pair) and offshore (right) series. Coastal specimens are USNM No. 395928, MMBL No. 65-1 and USNM No. 261432 (skull is mislabeled in photo). Offshore specimens are USNM No. 395464, 395463 and 395467.

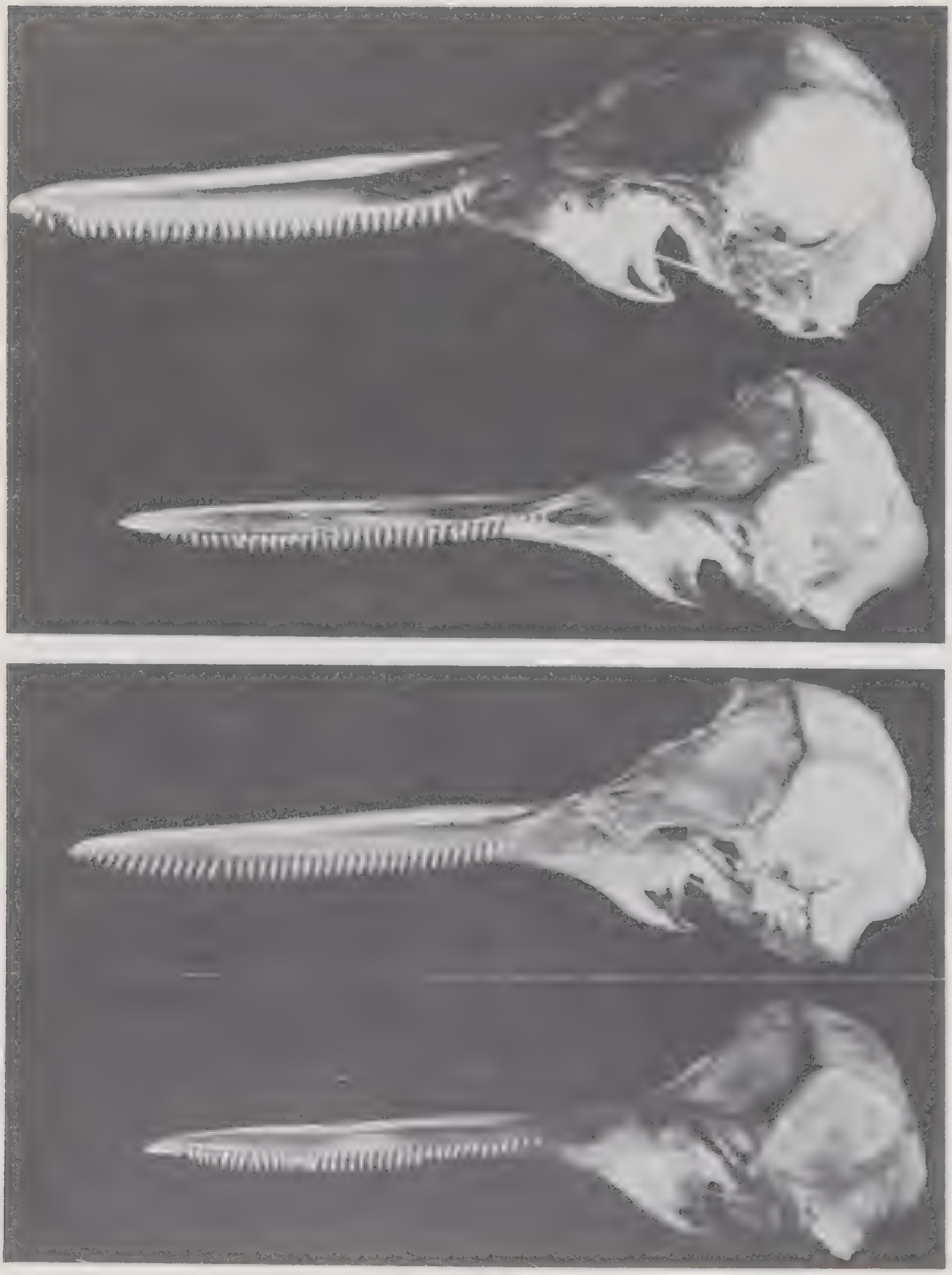

Figure 45. Lateral view of skulls in figure 44 (longest at top, modal at bottom). Coastal specimen at top in each pair (continued).

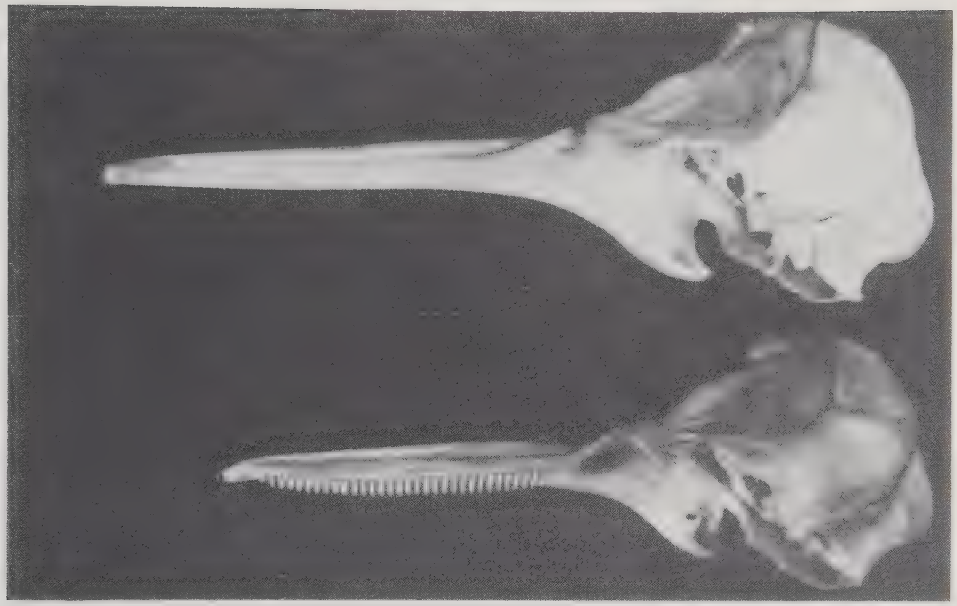

Figure 45 (continued). Lateral view of shortest skull in figure 44. Coastal specimen at top.

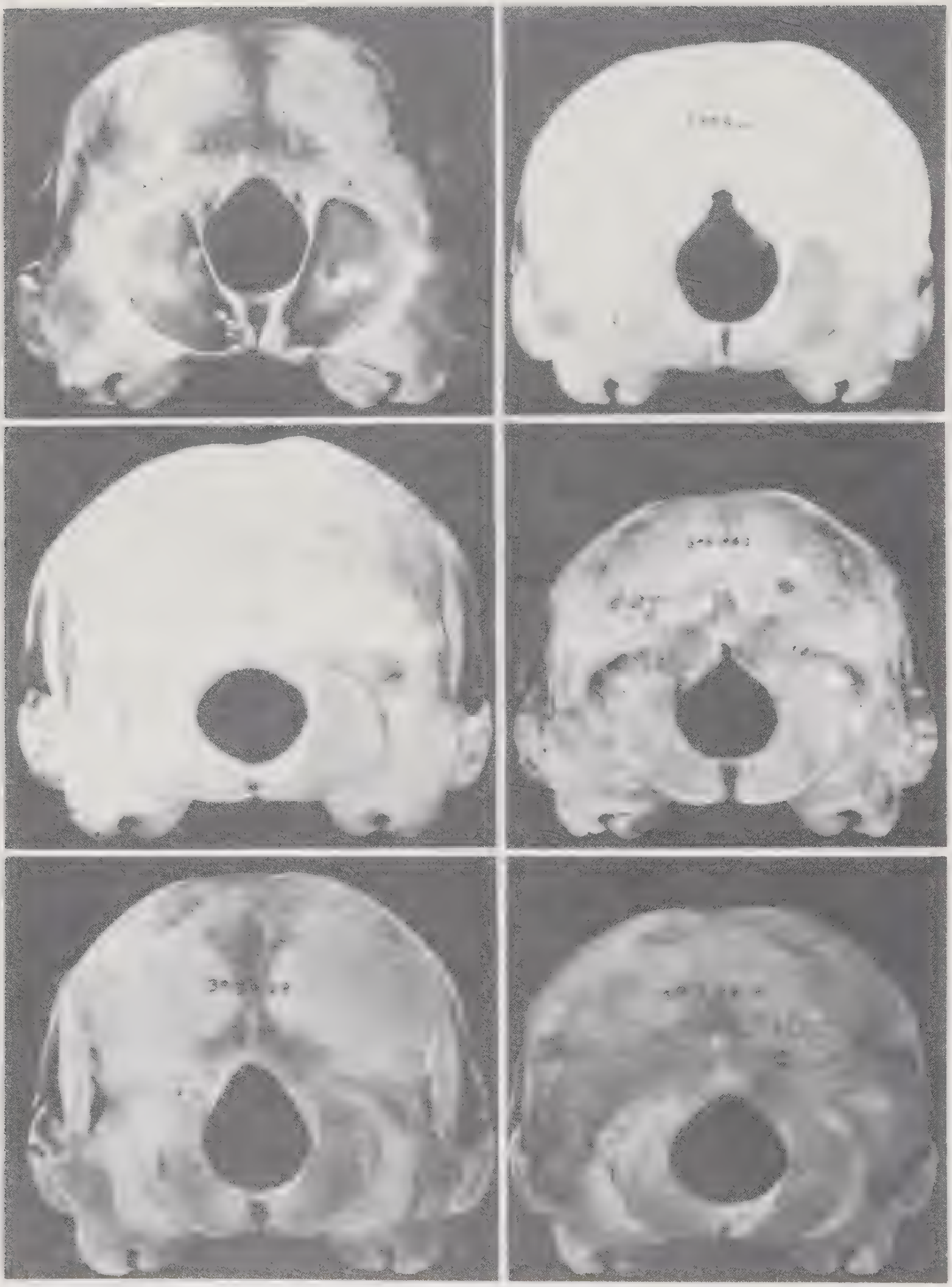

Figure 46. Occipital view of skulls in figure 44 (longest at top, modal in center, shortest at bottom). Coastal specimen at left in each pair.

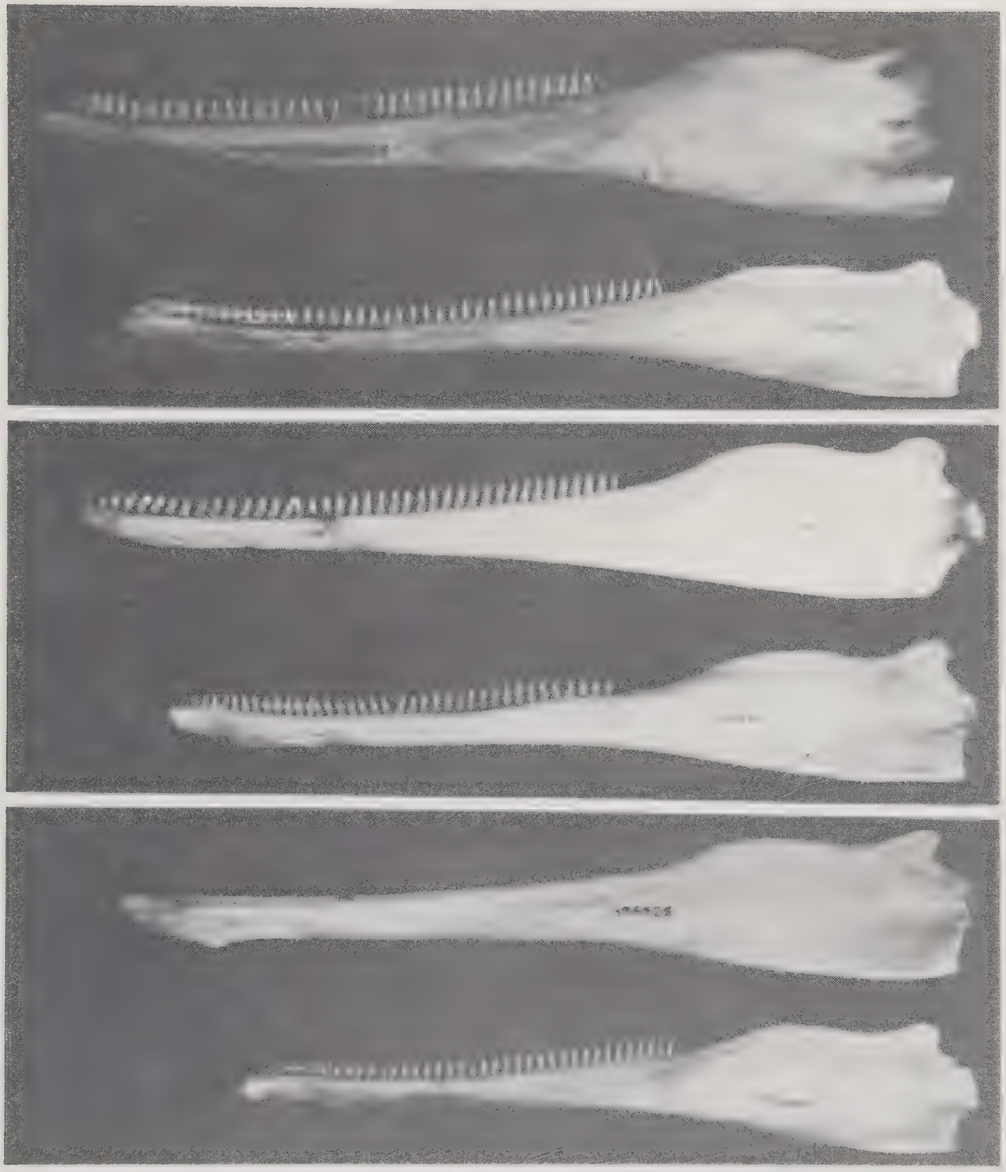

Figure 47. Lateral view of mandible of skulls in figure 44 (longest at top, modal in center, shortest at bottom). Coastal specimen at top in each pair.

Table 13a. Skeleton measurements and meristics of coastal and offshore adult spotted porpoise, with statistical comparisons of means (continued)

Variable	Unit	COASTAL				OFFSHORE				Absolute value of significant t, at $\alpha = .05$
		Number of specimens	Range	Mean	Standard deviation	Number of specimens	Range	Mean	Standard deviation	
1. Condylobasal length	mm	18	419-460	436.9	10.81	68	356-411	389.9	12.25	14.81
2. Rostrum length	mm	17	249-275	261.1	6.32	68	210-249	232.2	9.69	11.66
3. Rostrum width at base	mm	18	82-100	90.3	4.85	70	74-91	82.1	3.56	8.06
4. Rostrum width at 60 mm	mm	17	56-77	64.8	5.84	70	46-63	55.4	3.33	8.85*
5. Rostrum width at midlength	mm	18	43-60	48.7	5.04	67	35-48	40.8	2.84	8.73*
6. Premaxillary width at rostral midlength	mm	18	20-32	26.4	2.96	67	17-28	22.2	2.25	6.56
7. Rostrum width at 3/4 length	mm	17	29-43	34.3	4.23	65	23-36	28.4	2.65	7.14*
8. Rostrum tip to external nares	mm	18	289-316	303.3	7.37	68	245-294	271.3	11.91	10.83*
9. Rostrum tip to internal nares	mm	17	293-320	306.3	7.47	66	243-293	272.9	11.57	11.28
10. Preorbital width	mm	17	153-178	161.2	7.97	69	134-163	146.0	5.20	9.63*
11. Postorbital width	mm	17	172-196	180.0	7.32	69	151-178	164.2	4.96	10.63*
12. Least supraorbital width	mm	18	150-177	159.1	8.41	70	131-160	144.5	5.18	9.27*
13. External nares width	mm	17	43-52	46.6	2.45	70	37-47	41.5	2.06	8.82*
14. Zygomatic width	mm	15	173-198	181.6	8.31	70	148-177	163.0	5.19	11.20*
15. Greatest width of premaxillaries	mm	18	66-76	71.7	2.63	70	57-71	64.9	2.84	9.11
16. Parietal width	mm	17	135-153	145.8	5.27	70	129-150	137.6	4.68	6.32
17. Braincase height	mm	17	97-113	105.8	4.02	70	87-107	96.3	4.21	8.42
18. Braincase length (M)	mm	8	123-136	130.0	5.10	37	110-123	117.4	3.33	8.79
(F)	mm	4	121-131	126.0	5.77	32	109-122	115.3	2.91	6.18
19. Posttemporal fossa length	mm	17	73-97	83.2	6.25	70	56-77	67.6	4.24	12.32*
20. Posttemporal fossa width	mm	17	55-79	65.4	5.82	70	46-63	52.8	3.33	11.88*
21. Temporal fossa major diameter	mm	14	40-51	46.0	2.93	70	35-44	38.8	1.81	
22. Temporal fossa minor diameter	mm	14	24-37	28.1	3.81	70	18-27	22.6	1.98	7.94*
23. Projection of premaxillaries	mm	13	13-24	17.6	2.84	50	12-25	17.8	2.82	
24. Nasals to crest (M)	mm	8	26-51	35.9	7.57	37	19-38	26.8	4.85	4.33
(F)	mm	4	24-36	31.5	5.45	33	17-31	23.3	3.57	4.11
25. Orbit length	mm	17	49-54	51.1	1.54	70	44-53	47.0	2.00	7.89
26. Antorbital process length	mm	17	34-51	41.4	4.43	70	30-42	35.6	2.38	
27. Internal nares width	mm	17	48-60	52.8	3.17	70	40-54	36.4	2.62	8.66

28. Pterygoid length	mm	13	61-75	68.4	4.22	65	55-76	62.8	4.53	4.11
29. Occipital overhang	mm	15	0-11	2.5	3.09	70	0-10	3.7	2.44	
30. Bulla length	mm	3	30-32	31.0	—	66	29-33	29.9	0.75	
31. Periotic length	mm	2	27-28	27.5	—	66	25-30	26.9	0.95	
32. Upper tooth row length	mm	18	215-240	228.9	7.05	67	180-220	201.8	9.22	11.57
TEETH:										
33. Upper left	no.	24	37-46	40.9	2.29	93	37-48	41.5	2.20	
34. Upper right	no.	24	37-46	40.8	2.37	93	37-47	41.4	2.19	
35. Lower left	no.	25	36-44	39.9	2.04	91	34-45	40.4	2.19	
36. Lower right teeth	no.	26	36-43	40.0	1.74	93	34-46	40.6	2.05	
37. Lower tooth row length	mm	18	202-242	225.2	9.01	65	177-220	195.8	9.08	12.18
38. Ramus length	mm	18	352-393	372.4	10.20	66	296-347	328.5	12.17	14.00
39. Ramus height	mm	19	73-97	65.9	3.84	69	50-62	56.8	2.30	13.03*
40. Mandibular fossa length	mm	14	108-120	114.7	3.62	70	90-124	104.0	5.58	6.87
41. Deviation from symmetry	degrees	16	4-11	7.3	2.21	69	0-10	6.5	3.11	
42. Basihyal length	mm	8	30-41	34.5	3.66	62	24-36	29.5	2.28	5.41*
43. Basihyl width	mm	8	34-47	38.3	4.77	61	26-42	34.1	2.91	3.54*
44. Thyrohyal width	mm	8	17-22	19.4	1.60	61	14-29	17.7	2.10	2.20
45. Thyrohyal length	mm	8	56-68	60.3	4.33	61	40-62	53.3	4.17	4.45
46. Stylohyal width	mm	8	11-13	12.1	0.83	61	9-15	11.9	0.95	
47. Stylohyal length	mm	8	65-78	74.1	4.39	61	57-78	69.4	4.01	3.09
48. Thoracic vertebrae	no.	8	15-17	15.5	0.76	77	15-17	16.0	0.60	
49. Lumbar vertebrae	no.	6	17-22	19.3	1.75	62	17-23	19.8	1.37	
50. Caudal vertebrae	no.	6	34-37	35.8	1.17	59	34-42	38.1	1.57	3.48
51. Total vertebrae	no.	9	77-79	77.7	0.87	61	77-83	80.8	1.32	6.81
52. Fused cervical vertebrae	no.	3	2-2	—	—	15	2-3	2.1	0.35	—
53. Atlas width	mm	3	88-90	—	—	16	73-84	77.8	2.96	—
54. Atlas height	mm	3	54-61	—	—	16	46-50	47.4	1.09	—
55. Atlas lateral process length	mm	2	26-28	—	—	16	18-25	21.3	2.27	—
56. Atlas neural spine length	mm	3	42-48	—	—	16	30-44	36.8	3.47	—
57. Atlas dorsal ridge height	mm	3	4-6	—	—	16	1-4	2.4	0.96	—
58. Atlas dorsolateral spine length	mm	3	0-3	—	—	16	0-14	3.2	4.10	—
59. Axis lateral process length	mm	3	23-25	—	—	16	16-25	19.5	2.22	
60. Cervical vertebrae incomplete	no.	3	0-1	—	—	14	0-3	0.5	0.85	—

*Variance homogeneous at $\alpha = 0.1$ but not at .05. Blank indicates variance nonhomogeneous; dash indicates t insignificant.

Table 13a (continued). Skeleton measurements and meristics of coastal and offshore adult spotted porpoise, with statistical comparisons of means

Variable	Unit	COASTAL				OFFSHORE				Absolute value of significant t, at $\alpha = .05$
		Number of specimens	Range	Mean	Standard deviation	Number of specimens	Range	Mean	Standard deviation	
61. Greatest ventrolateral cervical process on	no.	3	6-6	—	—	15	5-6	5.9	0.21	—
62. First vertical foramen on	no.	9	53-57	54.3	1.22	81	52-61	57.2	1.62	5.20
63. First vertebra with reduced metapophyses	no.	8	30-33	31.4	1.06	76	24-35	31.3	2.39	—
64. Last transverse process on	no.	10	60-62	60.7	0.82	78	59-66	62.9	1.30	5.21
65. Last neural spine on	no.	10	65-67	65.8	0.79	77	64-71	68.1	1.26	5.61
68. First caudal with vertical spine	no.	10	56-62	59.1	1.60	77	56-64	60.8	1.50	3.35
69. First thoracic neural spine length	mm	3	28-42	—	—	16	9-37	24.9	8.50	—
70. Second thoracic neural spine length	mm	3	45-53	—	—	16	32-44	39.3	3.79	—
71. Tenth thoracic neural spine length	mm	2	60-78	—	—	16	55-70	62.3	5.02	—
72. Last thoracic neural spine length	mm	3	78-91	—	—	15	63-81	72.1	5.28	—
73. First thoracic vertebra height	mm	2	51-60	—	—	16	44-51	46.9	1.88	—
74. First thoracic vertebra width (M)	mm	2	79-82	—	—	8	68-80	73.6	4.28	—
(F)		0	—	—	—	8	63-76	70.0	4.14	—
75. First lumbar vertebra height	mm	2	57-67	—	—	15	46-52	48.9	1.71	—
76. First lumbar vertebra width	mm	2	189-207	—	—	15	165-188	174.8	6.34	—
77. 23rd centrum length	mm	2	24-27	—	—	14	19-25	21.1	1.75	2.64
78. Left vertebral ribs	no.	7	15-16	15.3	0.49	68	15-17	15.9	0.58	2.64
79. Right vertebral ribs	no.	8	15-17	15.5	0.76	66	15-17	15.9	0.59	—
80. Left 2-headed ribs	no.	11	4-6	5.4	0.67	84	4-7	5.5	0.75	—
81. Right 2-headed ribs	no.	11	4-6	5.3	0.79	83	4-7	5.6	0.72	—
82. Left floating ribs	no.	8	1-1	1.0	0	65	0-2	1.1	0.54	—
83. Right floating ribs	no.	8	1-1	1.0	0	64	0-2	1.1	0.53	—
84. Left sternal ribs	no.	7	8-10	9.1	0.69	62	8-11	9.4	0.62	—
85. Right sternal ribs	no.	7	9-10	9.1	0.38	60	8-11	9.4	0.63	
86. First vertebral rib length	mm	3	126-143	—	—	16	100-119	110.6	5.69	—
87. First vertebral rib width (M)	mm	2	19-27	—	—	7	20-24	31.6	1.40	—
(F)		0	—	—	—	8	16-22	18.4	2.26	—
88. Longest vertebral rib length	mm	3	281-313	—	—	16	232-263	248.9	9.04	—
89. First sternal rib length	mm	3	80-85	—	—	16	66-85	76.3	5.03	—

90. Manubrium width	mm	3	104-106	—	—	16	63-97	84.0	8.25	—
91. Manubrium length	mm	3	62-72	—	—	16	46-95	57.3	11.09	—
92. Manubrium notch depth	mm	3	6-10	—	—	16	5-19	9.6	3.24	—
93. Manubrium foramen length	mm	3	2-8	—	—	16	0-11	3.6	3.67	—
94. Mesosternal elements	no.	2	3-4	—	—	13	2-3	2.7	0.48	—
95. Mesosternals fused	no.	2	1-2	—	—	15	1-3	1.7	0.62	—
96. Chevron bones	no.	0	—	—	—	53	26-33	30.0	1.50	—
97. Chevron bones fused in first series	no.	2	2-2	—	—	15	0-4	2.2	1.08	—
98. First chevron on	no.	6	41-44	42.5	1.38	66	41-47	43.7	1.26	2.22
99. Last chevron on	no.	0	—	—	—	59	70-77	72.6	1.45	—
100. First chevron length	mm	2	10-14	—	—	14	3-23	9.3	5.22	—
101. Longest chevron length	mm	2	56-56	—	—	16	40-49	44.7	2.87	—
102. Last chevron length	mm	0	—	—	—	11	2-4	3.0	0.63	—
103. Scapula height	mm	3	130-135	—	—	16	101-123	108.2	5.82	—
104. Scapula length	mm	3	121-128	—	—	16	99-124	107.5	6.73	—
105. Coracoid length	mm	3	37-39	—	—	16	26-38	30.6	2.80	—
106. Coracoid width	mm	3	22-27	—	—	16	10-30	18.7	4.87	—
107. Metacromion width	mm	3	42-57	—	—	16	24-51	40.9	7.41	—
108. Humerus length	mm	3	54-62	—	—	16	43-53	48.1	2.41	—
109. Humerus width	mm	3	41-44	—	—	16	32-36	34.0	1.15	—
110. Radius length	mm	3	74-77	—	—	16	56-67	61.9	2.86	—
111. Radius width	mm	3	36-40	—	—	16	27-34	30.8	1.77	—
112. Ulna length	mm	3	63-65	—	—	15	48-61	54.4	3.02	—
113. Carpal row width	mm	3	67-73	—	—	14	49-62	55.8	4.28	—
PHALANGES:										
114. Digit I (M)	no.	2	2-2	—	—	7	2-2	2.0	0	—
(F)		0	—	—	—	6	1-2	1.8	0.54	—
115. Digit II	no.	8	6-7	6.5	0.53	73	7-9	7.5	0.58	4.66
116. Digit III	no.	7	4-5	4.6	0.53	71	4-6	5.1	0.42	2.94
117. Digit IV	no.	6	1-2	1.5	0.56	72	2-3	2.1	0.26	4.88
118. Digit V	no.	6	0-1	0	0.89	70	0-1	0.6	0.48	2.72
119. Pelvic length (left) (M)	mm	1	80	—	—	6	58-81	75.0	12.95	—
(F)		0	—	—	—	7	51-81	62.3	10.86	—
120. Pelvic length (right) (M)	mm	0	—	—	—	6	58-81	73.7	8.64	—
(F)		0	—	—	—	7	52-86	62.0	12.04	—

Table 13b. Skeleton measurements and meristics of Hawaiian spotted porpoise, with statistical comparison with offshore series

Variable	Unit	Number of specimens	Range	Mean	Standard deviation	Absolute value of significant t, at $\alpha = .05$
1. Condylobasal length	mm	12	395-440	413.6	12.36	6.17
2. Rostrum length	mm	12	240-269	250.8	9.08	6.18
3. Rostrum width at base	mm	13	86-94	89.2	2.27	6.91
4. Rostrum width at 60 mm	mm	13	58-66	62.5	2.54	7.29
5. Rostrum width at midlength	mm	12	43-49	45.9	1.93	5.96
6. Premaxillary width at rostral midlength	mm	12	21-27	24.4	1.98	3.17
7. Rostrum width at 3.4 length	mm	12	28-35	31.8	2.08	4.20
8. Rostrum tip to external nares	mm	12	274-321	293.4	12.31	5.90
9. Rostrum tip to internal nares	mm	12	273-318	294.1	11.40	5.85
10. Preorbital width	mm	13	149-164	158.0	5.31	7.61
11. Postorbital width	mm	13	163-182	173.6	5.80	6.10
12. Least supraorbital width	mm	13	145-162	155.6	5.58	7.01
13. External nares width	mm	13	38-46	42.3	2.10	—
14. Zygomatic width	mm	13	164-181	172.2	5.75	5.77
15. Greatest width of premaxillaries	mm	13	65-71	68.9	1.93	4.86
16. Parietal width	mm	13	135-150	141.0	4.83	2.39
17. Braincase height	mm	13	91-109	98.0	5.26	—
18. Braincase length (M)	mm	7	112-121	117.0	3.06	—
(F)	mm	2	118-119	—	—	—
19. Posttemporal fossa length	mm	13	57-70	62.0	4.24	4.37
20. Posttemporal fossa width	mm	13	42-56	50.2	3.80	2.53
21. Temporal fossa major diameter	mm	11	35-41	38.8	1.78	0
22. Temporal fossa minor diameter	mm	11	22-27	24.0	2.00	2.18

23. Projection of premaxillaries	mm	9	16-24	20.7	2.45	2.89
24. Nasals to crest (M)	mm	7	16-32	24.3	4.99	—
(F)	mm	2	19-29	—	—	—
25. Orbit length	mm	13	46-56	50.1	2.75	4.82
26. Antorbital process length	mm	13	35-42	38.2	2.20	3.66
27. Internal nares width	mm	13	44-55	48.7	2.95	2.85
28. Pterygoid length	mm	12	60-79	67.5	5.68	3.17
29. Occipital overhang	mm	13	1-14	5.8	3.36	2.68
30. Bulla length	mm	12	30-33	31.2	1.15	5.05
31. Periotic length	mm	11	25-29	27.8	1.36	2.72
32. Upper tooth row length	mm	12	200-232	215.9	8.43	4.94
TEETH:						
33. Upper left	no.	11	38-44	41.5	1.92	—
34. Upper right	no.	12	38-44	42.3	1.60	—
35. Lower left	no.	13	36-42	39.9	2.06	—
36. Lower right	no.	13	36-42	39.9	1.71	—
37. Lower tooth row length	mm	12	200-236	210.9	9.75	5.23
38. Ramus length	mm	12	339-379	351.4	11.63	6.03
39. Ramus height	mm	13	53-61	57.5	2.26	—
40. Mandibular fossa length	mm	11	102-114	106.6	3.23	—
41. Deviation from symmetry	degrees	13	5-10	7.1	1.62	—
42. Basihyal length	mm	7	27-37	32.4	2.99	3.09
43. Basihyal width	mm	7	34-42	38.0	2.77	3.37
44. Thyrohyal width	mm	7	16-23	19.1	2.54	—
45. Thyrohyal length	mm	7	49-64	56.3	5.22	—
46. Stylohyal width	mm	8	11-15	13.0	1.51	2.85
47. Stylohyal length	mm	8	68-77	71.9	3.64	—

The coastal series is more variable than the offshore series in most measurements, and the Hawaiian series is very small, making statistical comparison difficult. In many measurements, however, there is complete separation, and differences between the series (table 13a and b) are obvious and certainly significant.

Cranial skeleton

The sample for cranial measurements is limited to specimens regarded as adults, by the criterion of having 5 or more layers in the postnatal dentine or, for skulls for which teeth have not been sectioned, by the criterion of distal fusion of the premaxillaries and maxillaries.

Braincase. The coastal and offshore series are not as divergent in dimensions of the braincase as they are in condylobasal length. In parietal width (no. 16 in table 13) the overlap is nearly complete (fig. 48). Disparity is greatest in braincase length for males (no. 18) and intermediate in braincase height (no.17).

The Hawaiian series (table 13b) overlaps the offshore series in all measurements and counts. The braincase of the Hawaiian form is on the average larger only in parietal width, and that but slightly.

Feeding apparatus. It is in the feeding apparatus that the two eastern Pacific groups are most divergent. This is best exemplified in length of the ramus (fig. 48), where there is no overlap. The porpoise groups are modally different in absolute length and widths of the rostrum (nos. 2-7). The disparity in width of the rostrum increases distally. The rostrum of the offshore form is thus on the average more attenuate. Average ratio of rostrum length to width at the base is nearly the same in the coastal and the offshore series (2.91 opposed to 2.84). The ratio of length to 3/4 width, however, is 5.41 (4.45-6.00) in the coastal and 5.74 (4.80-6.56) in the offshore series. The two series are similar in tooth counts, but the tooth rows are longer in the coastal series. The teeth in the coastal skulls are on the average larger than in the offshore skulls, both in length and diameter. Length is difficult to measure in a consistent fashion because of differential wear at the tip of the tooth, but diameter can easily be measured uniformly in a transverse direction at the alveolus. This measurement, taken at midlength of a maxillary tooth row, shows overlap for the two groups but pronounced modal difference (fig. 48).

The temporal fossa (nos. 19-22) is much larger in the coastal form, but with overlap in the ranges of all four dimensions. The mean area of muscle attachment calculated as $\pi[(\text{ave. length + average width of fossa})/4]^2$ is 43.4 cm^2 in the coastal specimens, as opposed to 28.5 cm^2 in the offshore form, an increase of 50%. The cross-sectional area of the fossa proper through which the temporal muscle passes, calculated similarly using measurements 21 and 22, is 10.8 cm^2 in the coastal specimens as opposed to 7.4 cm^2 in the offshore specimens, an increase of 46%. This considerable disparity in size of the temporal fossa, and presumably in strength of jaw closure, influences the breadth of the skull across the processes enclosing the fossa, namely, the postorbital process and the zygomatic process. Consequently, the differences between the two groups in these widths (nos. 11 and 14) are relatively greater than in parietal width (no. 16), with less overlap.

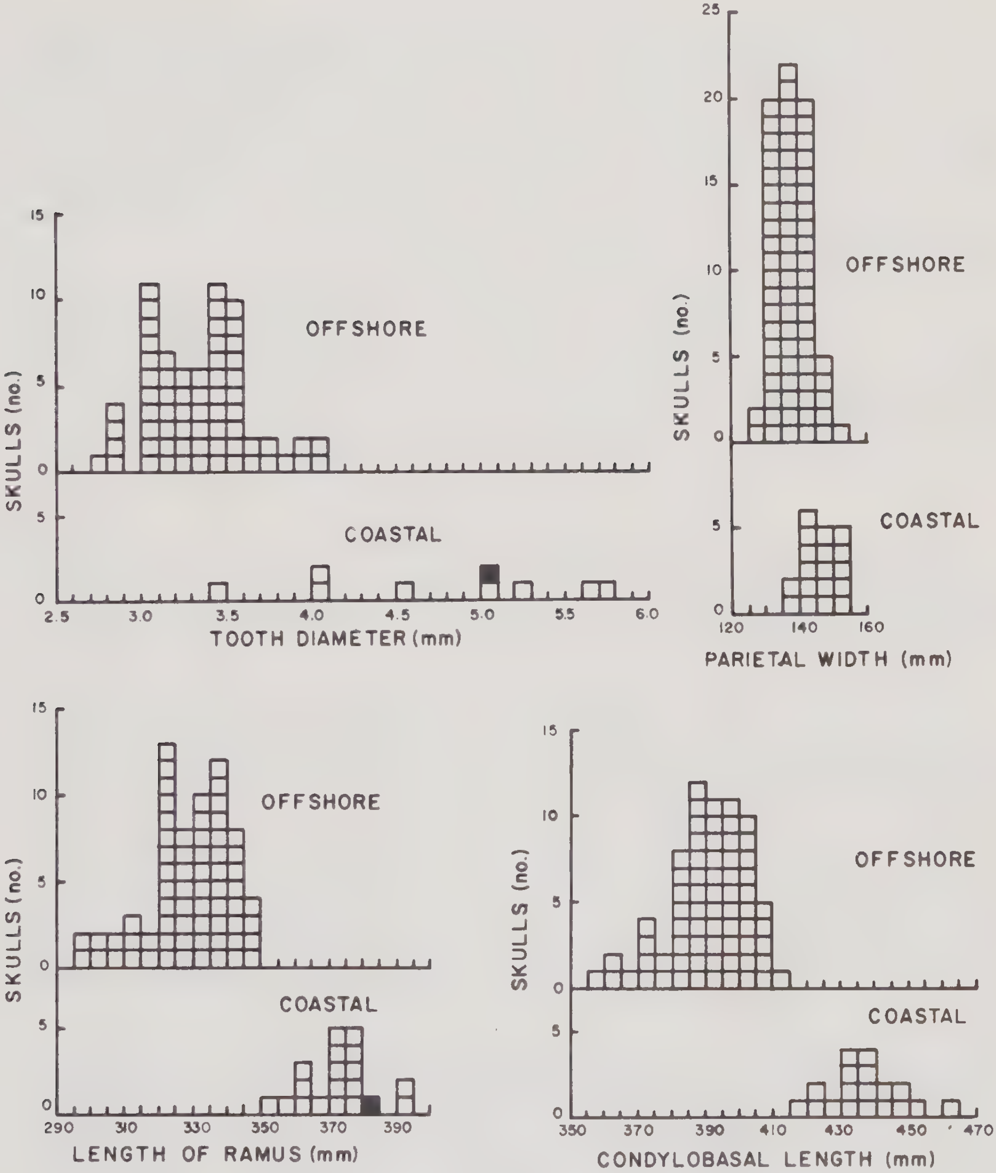

Figure 48. Comparisons of skull measurements of coastal and offshore series of spotted porpoise: (upper left) tooth diameter, (upper right) parietal width, (lower left) length of ramus, (lower right) condylobasal length. Blackened square represents type specimen of *Stenella graffmani* (Lönnberg).

The basihyal and thyrohyals (nos. 42-43) are less disparate between the groups than are the other elements of the feeding complex. This probably reflects their functions in breathing and/or sound producing as well as feeding. The stylohyals, known to function in the breathing and sound-producing apparatus as the origin of the stylopharyngeal muscle, are very similar in the two series. Width of the stylohyal (no. 46) is one of the four adequately sampled skull measurements (the others are projection of premaxillaries–no. 23, occipital overhang–no. 29, and deviation from symmetry–no. 41) for which the means for the two series are not significantly different at $\alpha = .05$.

The Hawaiian series differs most from the offshore series in the feeding apparatus. The Hawaiian animal has a longer, broader rostrum, both absolutely and proportionately, but tooth count and diameter are the same and the posttemporal fossa is on the average smaller, indicating a lesser development of the temporal muscle. Tooth diameter in 10 adult skulls ranges from 3.1 to 3.9 mm (average 3.35). This is entirely contained in the range of the offshore series and overlaps the coastal series by only one specimen.

Vision apparatus. The orbit (no. 25) is longer in the coastal form, but the differential is not as great as in condylobasal length and dimensions of elements of the feeding apparatus. The orbit is also longer in the Hawaiian form but not when taken as percentage of condylobasal length.

Hearing apparatus. The three ear bones available for the coastal series in both measurements (nos. 30 and 31) fall within the ranges for the offshore series. The ear bones of the Hawaiian series are larger absolutely but not larger relative to condylobasal length.

Breathing and sound-producing apparatus. Divergence in width of the premaxillary shield (no. 15) and width of the external and internal nares (nos. 13 and 27) is not as great as for most elements of the feeding apparatus. Most divergent is length of the preorbital process (no. 26), and least divergent are length and width of the stylohyals (nos. 46 and 47). There is overalp between the series in all aspects of this system, and complete correspondence in at least one measurement, width of the stylohyal.

Summary. The differences in skull measurements between the coastal and offshore series are greatest in the feeding apparatus (fig. 49) and can be summarized in an analog fashion in terms of the functional systems, using values of Student's t (fig. 50). Excluded are measurements that are extremely variable, including projection of premaxillaries (no. 23) and occipital overhang (no. 29); and those for which it would appear that size is not most influenced by the functional unit to which they belong or for which the functional relationship is unclear, including length of the mandibular fossa (no. 40) and pterygoid length (no. 28). This demonstrates that the difference between the coastal and offshore forms is not one of size alone but of proportion as well. The feeding apparatus is proportionately more disparate in the two groups than are the other functional systems. My interpretive hypothesis follows. The major selection pressure impinging on skull size and proportion has to do with feeding. A more robust feeding apparatus

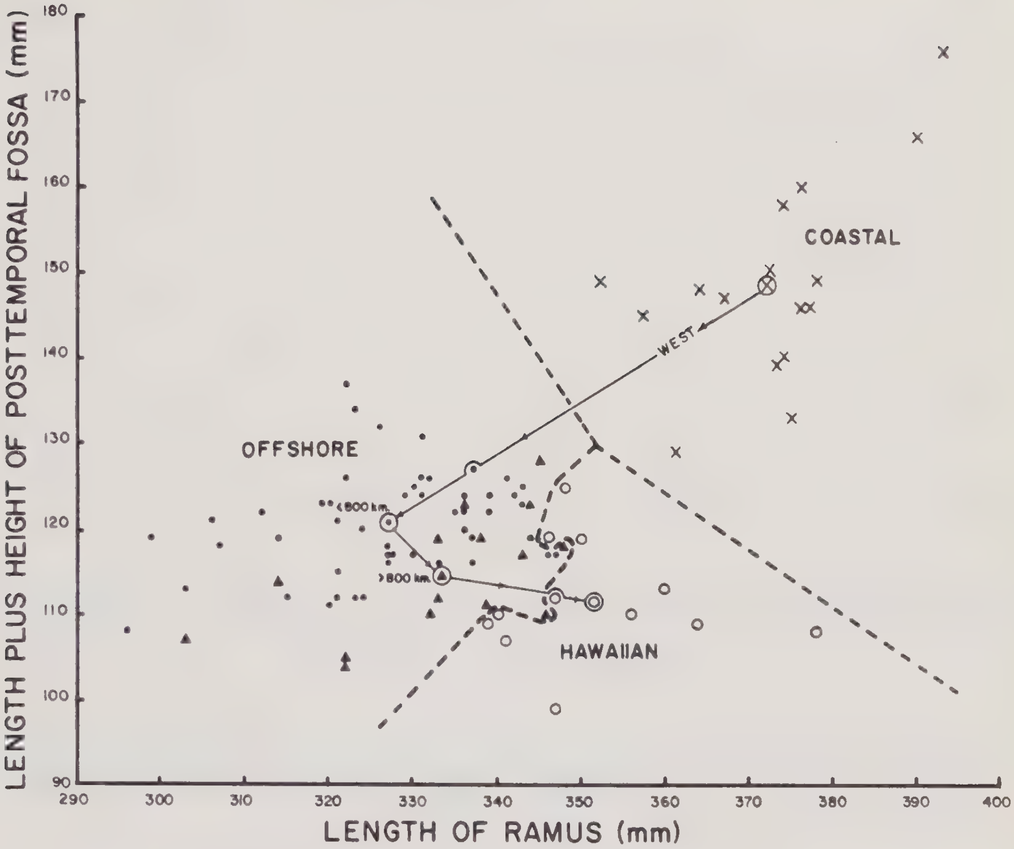

Figure 49. Geographical variation in the skull of the spotted porpoise in eastern Pacific and Hawaiian waters. Circled symbols are series means.

is advantageous along the coast where available prey, including demersal fishes, may be larger and more irregularly and heavily constructed than offshore. A smaller, more finely constructed feeding apparatus and greater maneuverability are favored in the pelagic habitat where the major diet items are small squid and small, streamlined, relatively defenseless but fast-moving fishes (exocoetids, myctophids, small scombrids, and others). The easiest route to a more robust or more lightly constructed feeding apparatus is along the independent general length and width axes that I defined and discussed above in the section on individual variation, with the emphasis on length. These axes also, to a lesser extent, influence the other systems, carrying them along behind the feeding apparatus. Homeostasis of nonfeeding elements of the skull probably operates through other selection vectors impinging on independent components of the variance associated with each system.

There is also geographical variation within the total offshore series, with the axis of variation oriented east and west. If the series be divided into those from within 800 km

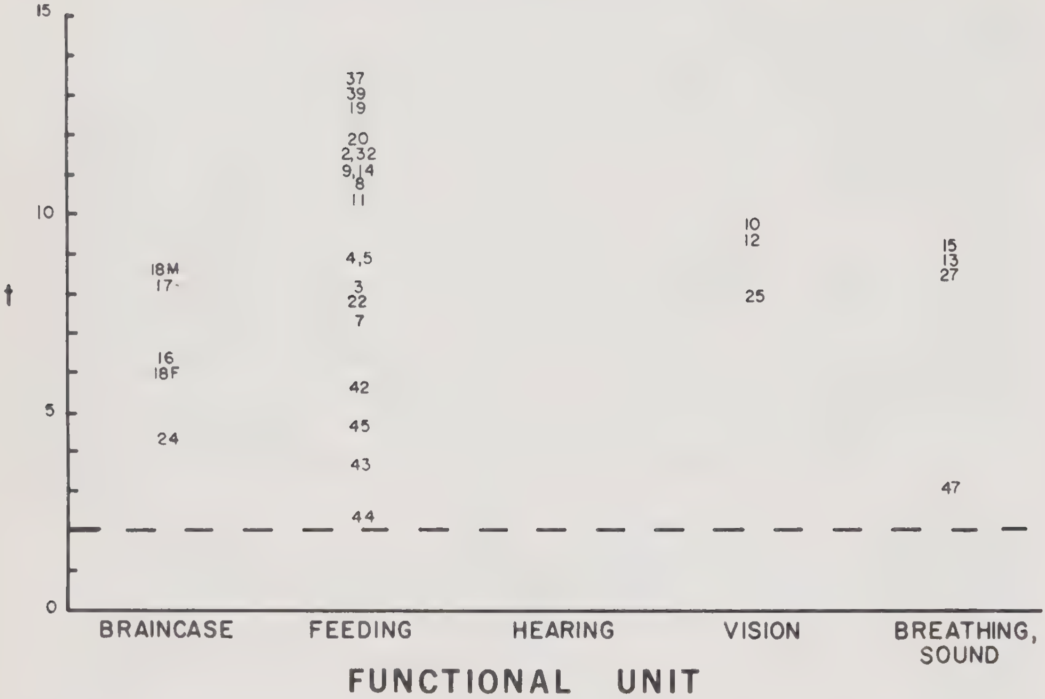

Figure 50. Comparative geographical variation of functional units of skull, in terms of Student's *t*, for coastal and offshore series of spotted porpoise. Measurements listed in table 2 and illustrated in figure 2. Compare with figure 40.

of the mainland (80 specimens) and those from more than 800 km from the mainland (25 specimens), the geographical trend becomes apparent. The 800 km limit falls roughly on a line extending from outside the Revilla Gigedo Islands to just inside Clipperton Island, and thence to Cocos Island. This also corresponds very roughly to the shoreward limit of distribution of the "whitebelly spinner" (see section below on *S. longirostris*). A similar division was used above in discussing trends in coloration and external morphometrics. For all the included skull measurements except length of the temporal fossa, the mean for the far offshore series is greater. The two series overlap in all measurements. The feeding, hearing, vision, and breathing and sound-producing apparatuses are all about equally divergent, but dimensions of the braincase are not affected, indicating a slight mean difference in skull proportions as well as size. An idea of the scope of the geographical variation within the offshore area relative to that between the coastal and offshore forms can be had by comparison of figure 51 with figure 50. The most divergent measurements among offshore specimens are widths, not lengths as in the coastal-offshore dichotomy.

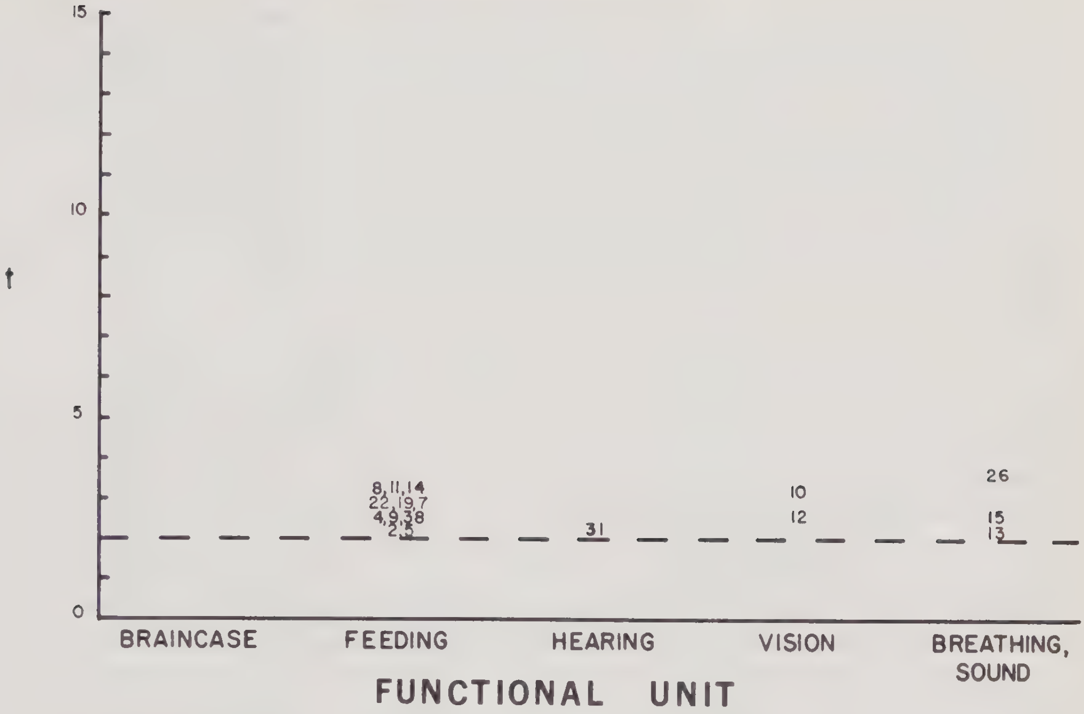

Figure 51. Comparative variation of functional units, of skull, in terms of Student's *t* between "offshore" and "far offshore" series of spotted porpoise.

The Hawaiian series continues the east-west trend within the offshore series and converges with the coastal series in condylobasal length and other measurements (fig. 49) reflecting length of the feeding apparatus. The offshore specimens from the westerly part of the range of the series are most Hawaiian like. Those to the east are both less Hawaiian like and sharply differentiated from the immediately adjacent coastal series. The dip in the curve yielded by connecting the four means left to right in figure 49 indicates that not only allometric growth is at work. The feeding apparatus does not simply become more robust proportionately as the skull becomes larger. Selection apparently impinges on a component of the variance in the feeding apparatus which is to some degree independent of a general size factor.

Postcranial skeleton

The series also differ in postcranial measurements. The sample is limited to physically mature specimens. The coastal series of mature skeletons is unfortunately very small, consisting of two from the Bay of Panama and the single specimen from Guaymas in the Gulf of California. As stated above, the difference in size between the coastal and offshore animals is most extreme at the northern and southern ends of the range, and these three skeletons in half the postcranial measurements are all larger than any of the 16 mature offshore skeletons measured (table 13).

The samples are somewhat larger for the meristic characters, including specimens of all ages, and here some disparity is also evident. Total number of vertebrae in the coastal series ranges from 77 to 79 (average 77.7) and in the offshore series from 77 to 83 (average 80.8). The two samples probably belong to different distributions (fig. 52). The offshore form has on the average a longer caudal series (no. 50). This is reflected also in the positions of the first vertical foramen (no. 62) and last transverse and neural processes (nos. 63 and 64). The three coastal specimens have forelimbs larger than those of the offshore specimens, but in the mesial three digits (nos. 115-117), hyperphalangy is greater in the offshore animals, a result that agrees well with the findings above for external length of the flipper.

The sample of mature skeletons from the far offshore region is too small to allow similar analysis of postcranial measurements, but variation is evident in the postcranial meristics. The specimens in the series from more than 800 km offshore tend to have fewer vertebrae (fig. 52) and different means for the positions of the first vertical foramen, last transverse process, last neural spine, and the first caudal vertebra bearing a vertical neural spine, which are all shifted posteriorly. When the far offshore specimens are subtracted from the distribution of vertebral number (fig. 49), the difference between the coastal form and the adjacent offshore form (including now only those within 800 km of the coast) becomes even more pronounced, with very little overlap. The animals from very far offshore, then, are more similar to the coastal form in skull size (except the temporal fossa) and vertebral meristics than are those from within 800 km. A reversal of this trend is indicated in the manus, in that hyperphalangy is the more developed in the far-offshore specimens in the offshore series (no. 115).

The sample sizes for postcranial measurements of the Hawaiian series are very small (only two physically mature specimens are available). Both specimens lie outside the range of the offshore series in width of the first thoracic vertebra, length of the longest rib, length of the first sternal rib, and length of the longest chevron. The larger of the two lies inside the range of the offshore series only in atlas width, length of the first thoracic neural spine, width of the first lumbar, width of the first vertebral rib, height of the scapula, widths of the humerus and radius, width of the first row of carpals, and lengths of the pelvics. These results indicate that the Hawaiian animal has a more massive skeleton with larger rib cage and broader flippers than does the offshore form, but examination of larger series is needed for confirmation. In meristics the Hawaiian ranges are all contained in the offshore ranges.

CLASSIFICATION AND DIAGNOSES

I conclude on the basis of the evidence presented above that the spotted porpoises in the eastern Pacific and in Hawaiian waters belong to a single species, with a possible gap in the distribution between the westernmost limits of the eastern Pacific populations and the Hawaiian population.

The relationships of the Hawaiian population with those in the southern and western Pacific and Indian Oceans badly need to be examined. True's (1889 and 1906) work remains the best on the group, and I therefore provisionally apply the name *Stenella attenuata* to the eastern Pacific and Hawaiian spotted porpoise, implying that a single species extends from the west coast of the Americas to at least the southern Atlantic and

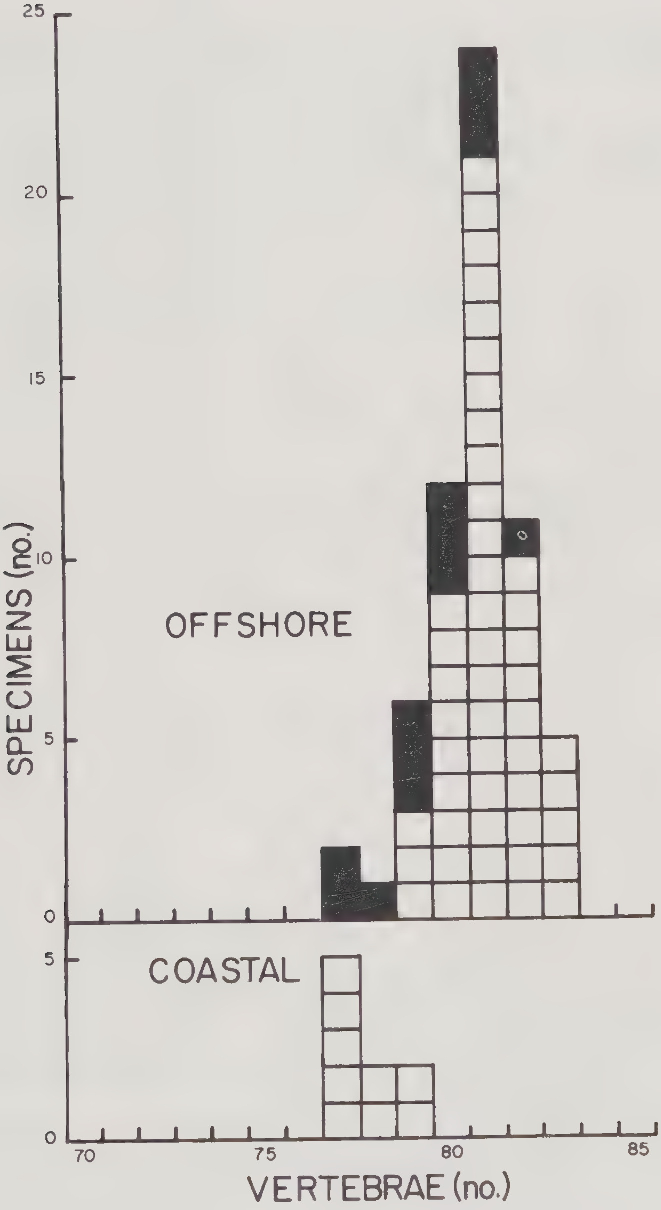

Figure 52. Comparison of vertebral counts of coastal and offshore porpoise. Shaded squares represent "far offshore" specimens.

that True was correct in referring Gray's (1846) type specimen to such a species. If and when series from the western and south Pacific, Indian, and southern Atlantic Oceans are compared to series of animals from the North Atlantic that have flipper-to-gape stripes, and as seems likely, found not to differ from them, then the name *S. frontalis* (G. Cuvier) shall apply. As discussed above, other earlier names are *dubia* G. Cuvier (revived by Rice and Scheffer, 1968), *pernettensis* Blainville (suppressed by van Bree, 1971*a*), *malayana* Lesson, and *velox* G. Cuvier, but these all seem destined for suppression because of inadequate descriptions and/or long-standing nonusage.

The series of coastal specimens examined here is discretely separable from the series of the offshore specimens in skeletal characters, but I provisionally relegate the coastal form to only subspecific status as *S. attenuata graffmani* for the following reasons: (1) The forms are allopatric and in contact, and the boundary between them has been determined in a rather arbitrary manner. In short, a cline may exist. (2) The series of coastal specimens is rather small (19 for cranial characters). It seems likely that examination of a larger series of coastal animals will reveal overlap in perhaps all of the characters in which there presently is separation. (3) Differences between the coastal and offshore series are most pronounced at the northern and southern extremes of the range, where there is apparent spatial separation of the forms (by Baja California in the north and a distributional hiatus in the south), suggesting that in the central reaches of the "boundary" there may be an inshore-offshore gene flow.

Whatever the future course of the taxonomy of the spotted porpoises may be, it seems likely that the coastal population will retain at least subspecific status, and that the name *graffmani* will apply to it. All of the holotypes of the other described species, except that of *S. plagiodon*, are outside the range (smaller) of the coastal form in several characters. As discussed above, the type of *S. plagiodon* almost certainly belongs to a different species, with a different basic color pattern.

The eastern Pacific offshore form deserves subspecific recognition relative to the populations to its east and west but cannot as yet be named. The type of *S. attenuata* falls well within the range of the offshore series in all skull measurements and proportions (measurements in True, 1889 and Fraser, 1950), but is from an unknown locality and of unknown external appearance. The same applies to the Hawaiian form (distributed within an unknown range to the west and south of Hawaii). I therefore provisionally refer to the two populations as *S. attenuata* subspecies A and B, respectively, either of which may or may not eventually prove to be *S. a. attenuata.*

A commonly used criterion of subspecific level difference between populations is whether or not 90% of the specimens can be unequivocally assigned to the proper group on morphological grounds (Mayr,1970). While such is obviously the case for the coastal versus the offshore and Hawaiian series of skeletal specimens (fig. 49), the situation is less clear cut for the offshore versus the Hawaiian series. Much better definition can be attained through the use of discriminant analysis. Using a stepwise discriminant analysis program (see Methods), discriminant functions were calculated by analysis of 25 measurements for 76 adult skulls (11 coastal, 53 offshore, and 12 Hawaiian). The computer program used does not provide for missing observations. Therefore, both to maximize the small coastal and Hawaiian samples and to maximize the number of measurements included, some measurements were deleted from the original list, and some damaged offshore skulls were not included in the analysis. Using the loading coefficients for the two discriminant functions (table 14), the 76 specimens and the group means were plotted on the discriminant axes (fig. 53). With this procedure, and using the criterion of nearest group mean, all 76 specimens can be correctly classified.

The possibility exists, of course, that the observed differences between the geographical series are manifestations of phenotypic responses to local environmental factors. It seems more likely, however, that the differences are genetic, and I chose this alternative as the basis for the following diagnoses.

Diagnoses of Subspecies of Spotted Porpoise, *Stenella attenuata* (Gray, 1846), of the Eastern Pacific and Hawaii

A. Eastern Pacific Coastal Spotted Porpoise, *Stenella attenuata graffmani* (Lönnberg, 1934).

Coloration. As described by Perrin (1970*b*), with dorsal spotting sparse to heavy (criteria defined in table 3), but medium to heavy in most specimens.

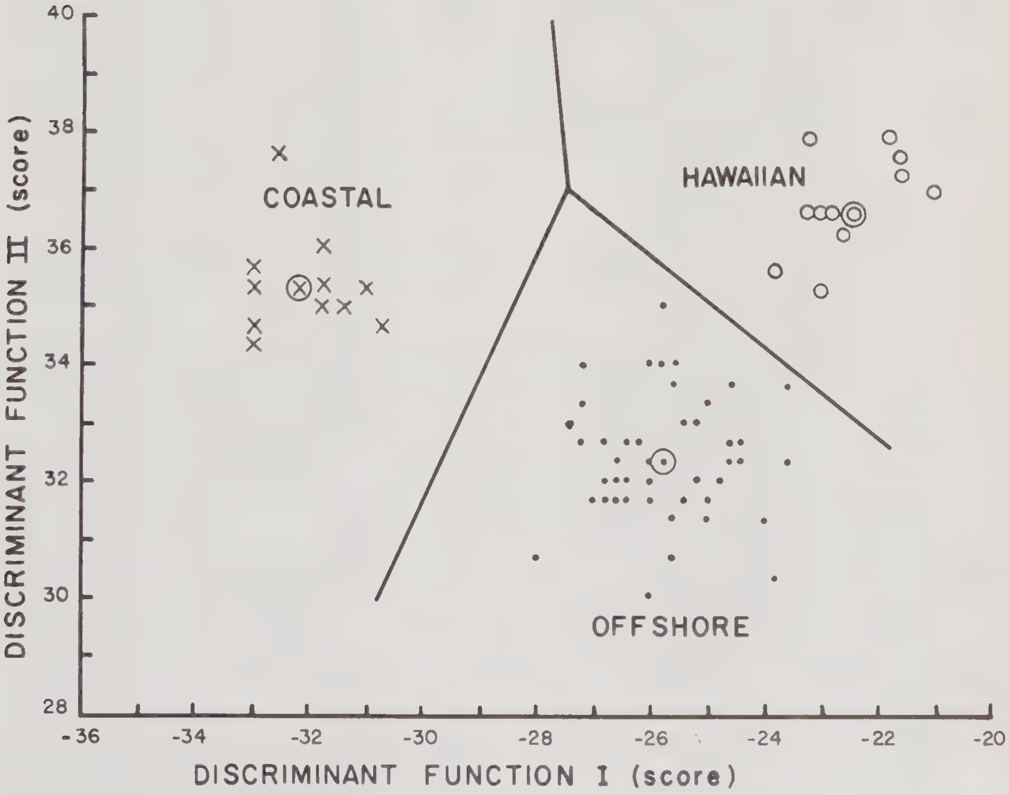

Figure 53. Geographical series of skeletal specimens of spotted porpoise plotted on discriminant functions based on 25 measurements. Circled symbols are series means.

Table 14. Loading coefficients for discriminant functions separating Coastal, Offshore, and Hawaiian series of crania of spotted porpoise. Measurement numbers refer to figure 2

Number	Measurement	Discriminant function I	Discriminant function II
1	Condylobasal length	-.04744	.00935
2	Length of rostrum	.18259	.14149
3	Width of rostrum at base	-.05059	.04348
4	Width of rostrum at 60 mm	.04468	.16630
5	Width of rostrum at midlength	-.27824	.13520
6	Width of premaxillaries at midlength of rostrum	.19415	-.01358
7	Width of rostrum at 3/4 length	.39112	-.19823
8	Tip of rostrum to external nares	-.12195	-.09233
9	Tip of rostrum to internal nares	.04816	-.01027
10	Preorbital width	.16880	.14772
11	Postorbital width	-.07486	-.07671
12	Least supraorbital width	-.06304	-.03383
13	Width of external nares	-.29585	-.07682
14	Zygomatic width	.02190	-.00923
15	Greatest width of premaxillaries	.06746	.16174
16	Parietal width	.16437	.03966
17	Height of braincase	-.13052	-.02017
18	Length of braincase	-.13047	-.02573
19	Length of posttemporal fossa	-.11854	-.03263
20	Width of posttemporal fossa	-.25754	-.03507
25	Length of orbit	.06786	.10140
27	Width of internal nares	.03393	-.05702
32	Length of upper toothrow	-.07245	-.02817
38	Length of ramus	-.03438	.03825
39	Height of ramus	-.10580	-.06551

External size and shape. Adults 2.0-2.6 m long; distance from tip of upper jaw to anterior end of flipper insertion (taken parallel to body axis) 41-44 cm (20-22% of body length), to center of eye 28-33 cm (13-17%).

Skeleton. Condylobasal length 419-460 mm; rostrum length 249-275 mm (168-196% parietal width); rostrum width at 60 mm, 56-77 mm (38-53% parietal width); ramus length 352-393 mm (242-270% parietal width); posttemporal fossa length 73-97 mm (51-65% parietal width); posttemporal fossa width 55-79 mm (37-53% parietal width); preorbital width 153-178 mm (105-124% parietal width); tooth diameter (transverse diameter at alveolus of tooth at midlength of maxillary row) 3.5-6.0 mm; total number of vertebrae 77-79; first perforating vertical foramen on vertebra no. 53-57; phalangeal formula for digits II-V: 6-7, 4-5, 1-2.

Range. Occurs within about 20-25 km of the shore on the open coast, and in gulfs and embayments, from Guaymas, Sonora, Mexico (Gulf of California) to Gorgona Island, Colombia, usually in small groups or schools or fewer than 100 individuals.

The type specimen of *S. graffmani* (Lönnberg, 1934) and the second specimen described by Lönnberg (1938) from the type locality, Acapulco, are of this subspecies; as are also the specimens reported on by Van Gelder (1960), Bowman (1958), Hall and Kelson (1959), Hershkovitz (1966), Neiland, Rice, and Holden (1970), and Miller and Kellog (1955). None examined from the tuna fishery are of this subspecies, although logbook records of net sets close to shore may indicate minor involvement. This form is called by tuna fishermen "humpback spotter" or "bull spotter" and is reputed not often to be associated with schools of tuna.

B. Eastern Pacific Offshore Spotted Porpoise, *Stenella attenuata* subspecies A (unnamed?).

Coloration. As described by Perrin (1970*a*), with dorsal spotting sparse to heavy (most specimens from more than 800 km offshore are sparsely spotted).

External size and shape. Adults 1.7-2.3 m long, tip of upper jaw to flipper insertion 38-42 cm (17-23% of body length), to center of eye 25-31 cm (13-17%).

Skeleton. Condylobasal length 356-411 mm; rostrum length 210-249 mm (149-186% parietal width); rostrum width at 60 mm, 46-63 mm (34-46% parietal width); ramus length 296-347 mm (213-261% parietal width); posttemporal fossa length 56-77 mm (41-55% parietal width); posttemporal fossa width 46-63 mm (33-44% parietal width); preorbital width 134-163 mm (98-118% parietal width); tooth diameter 2.7-4.1 mm; total number of vertebrae 77-83 (only the specimens from more than 800 km offshore have been found to have 77-78 vertebrae); first vertical foramen on vertebra no. 52-61; phalangeal formula for digits II-IV: 7-9, 4-6, 2-3.

Range. Occurs from about 25 km offshore on the open coast from Cabo San Lucas, Baja California del Sur, Mexico, to Colombia, west to at least 145°W longitude in tropical waters. May occur seasonally as far north as Bahia Sebastian Vizcaino. Occurs in schools of from a few individuals to several thousand.

This form is heavily involved in the tropical tuna seine fishery (Perrin, 1970a). Specimens belonging to this subspecies include those referred to *Stenella fraffmani* in Boice, Swift, and Roberts (1964), Dailey and Brownell (1972), Dailey and Perrin (1973), Daugherty (1966), Evans and Prescott (1962), Fitch and Brownell (1968), Green, Perrin and Petrich (1971), Harrison (1969a and b), Harrison, Boice, and Brownell (1969a and b), Harrison, Johnson and Tedder (1967), Mitchell (1970), Nishiwaki (1966, 1967), Perrin (1968, 1969, 1970a, 1970b), Perrin and Hunter (1972), Perrin and Orange (1971), Perrin and Roberts (1972), and Pilson and Waller (1970).

Of the three subspecies defined here, only this one brackets the holotype of *S. attenuata* (Gray 1846)–from unknown locality–in all skull measurements and proportions. The holotype in condylobasal length falls within the range of only this subspecies (when larger series of the coastal and Hawaiian forms become available, this situation may no longer obtain).

C. Hawaiian Spotted Porpoise, *Stenella attenuata* subspecies B (unnamed?).

Coloration. Ground pattern (everything except spots) as described by Perrin (1970*a*). In contrast with the eastern Pacific subspecies (described above), the cape is darker and lateral field lighter, yielding a more pronounced contrast. Only subadults are noticeably spotted (ventrally); dorsal spots are absent or sparse, and in the adult the ventral mottling present in eastern Pacific subspecies is so faint as to be hardly noticeable.

External size and shape. Adults 1.8-2.1 m, tip of upper jaw to flipper insertion 37-42 cm (19-24% body length), to center of eye 29-33 cm (14-18% body length).

Skeleton. Condylobasal length 395-440 mm; rostrum length 240-269 mm (163-194% parietal width); rostrum width at 60 mm, 58-66 mm (40-48% parietal width); ramus length 339-379 mm (233-257% parietal width); posttemporal fossa length 57-70 mm (41-48% parietal width); posttemporal fossa width 42-56 mm (30-38% parietal width); preorbital width 149-164 mm (104-118% parietal width); tooth diameter 3.1-3.9 mm; total number of vertebrae 79 (two specimens examined); first vertical foramen on vertebra no. 54-56 (four specimens); digits II-IV: 8, 6, 3 (two specimens).

Range. Occurs in Hawaiian waters to an unknown distance offshore. Has been observed between the islands and at Penquin Bank off Molokai (personal communication, K.S. Norris).

Relationships between this form and the dorsally more spotted form(s) in the southern and western Pacific have not been investigated. Porpoise from Hawaiin waters referred in the literature to *S. attenuata* are of this subspecies.

Specimens from unknown localities in the eastern Pacific may also be classified by application of the discriminant functions in table 14 and comparison of the scores with the scatterplot in figure 53.

Summary of Differences between the Subspecies

Differences between the subspecies can be summarized in qualitative terms. The coastal form is on the average larger and more spotted than the offshore and Hawaiian forms. The Hawaiin form is less spotted and has a proportionately larger head than the offshore form. The coastal form has the fewest vertebrae, the offshore form has the most. The skull of the coastal form is large and massive, that of the offshore form is small and more lightly built, and that of the Hawaiin form is large and lightly built. The coastal form is largely neritic, the offshore form inhabits the high seas, and the Hawaiian form frequents the oceanic Hawaiian Islands.

SPINNER PORPOISE

The spinner porpoise is the second most important delphinid involved in the tuna fishery, after the spotted porpoise. Knowledge about the spinner porpoise in the eastern tropical Pacific was also very scanty before the United States government began to investigate their biology because of their involvement in the tuna fishery. Only three records of spinner porpoise in the eastern Pacific were published before these studies began in 1967. Nelson (1889) reported sighting schools of long-snouted animals near the Tres Marias Islands and referred them to *Prodelphinus* [= *Stenella*] *longirostris* (Gray 1828). He collected a specimen that was later referred to *S. microps* (Gray 1846) by Miller and Kellogg (1955). True (1889) reported on a specimen collected from the research vessel *Albatross,* "in the Pacific Ocean, between the Galápagos Islands and Panamá." Beddard (1900) included the Gálapagos Islands in the range of *Prodelphinus longirostris* but did not specify the basis for so doing. It seems likely that the Galápagos were included on the basis of True's record from "between Panamá and the Galápagos" [not "halfway between the Isthmus of Panamá and the Galápagos" (translation: Cabrera and Yepes, 1940) or "near the Galápagos Islands" (Roberts, 1951)] . There is, then, no evidence that spinners occur near the Galápagos. True's record probably also forms the basis for inclusion of *S. longirostris* in other faunal lists for the west coast of South America, such as Mann's (1957). Hershkovitz listed *S. longirostris* from Chile (Cape Horn) according to Beddard (1900), but Beddard did not include Chile in the range. The southernmost published record, therefore, is some point "between Panamá and the Galápagos Islands," and there is certainly no basis whatsoever for Marcuzzi and Pilleri's (1971) mapping of the range of *S. longirostris* as extending from Cabo San Lucas to Cape Horn.

The third early published record for the eastern tropical Pacific of spinners was by Hester, Hunter, and Whitney (1963), who referred them to *S. microps* (Gray 1846). The identification was made by C.O. Handley, Jr., and was based on specimens from off Guatemala.

The area of the yellowfin tuna fishing grounds involving spinners (fig. 54) corresponds very closely to that for the spotted porpoise (fig. 3), with a slightly lesser extension to north and south. The majority of net sets in the IATTC data were made on mixed "schools" of spotted and spinner porpoise.

The distribution of more reliable records (fig. 55) also conforms closely to that for the spotted porpoise (fig. 4). Again there is the apparent gap between the westernmost limits of the range of the eastern Pacific forms and Hawaiian waters where spinners, referred variously to *Stenella longirostris* (Gray) and to *S. roseiventris* (Wagner), occur (Perrin, 1972).

HISTORICAL REVIEW

Atlantic Ocean

Pernetty (1769) was the first to record observations of a spinner porpoise, as well as of a spotted porpoise. The animals, seen six days after passing Boa Vista in the Cape Verde Islands (6°43 N, 25°17 W, fide Fraser, 1950) "leaped at least three or four feet

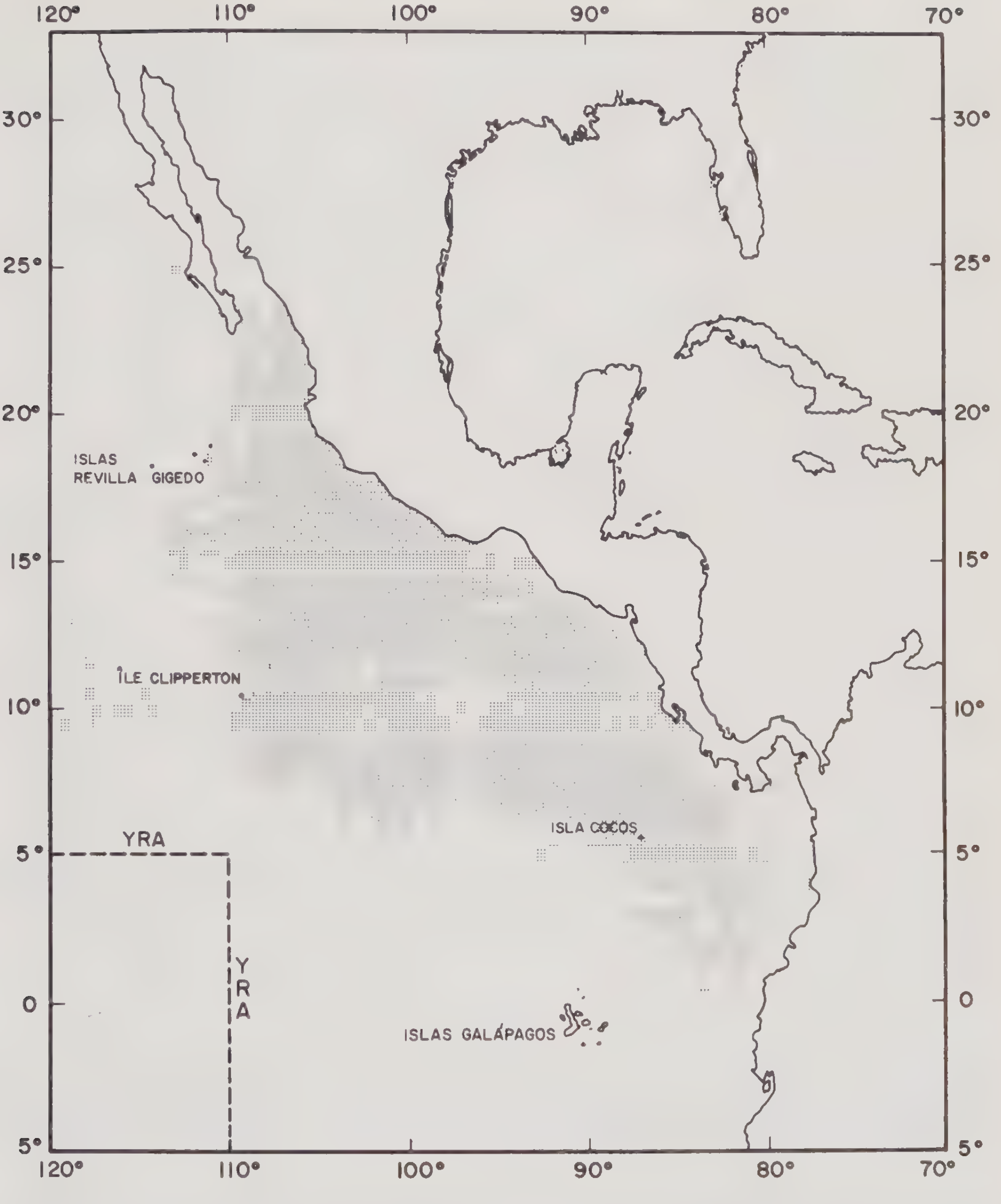
120°
110°
100°
90°
80°
70°
30°
25°
20°
15°
10°
5°
0
5°
ISLAS REVILLA GIGEDO
ÎLE CLIPPERTON
ISLA COCOS
ISLAS GALÁPAGOS
YRA
YRA

Figure 54. Distribution of purse seine net sets on spinner porpoise in the Commission Yellowfin (tuna) Regulatory Area, 1963-1970, by 1/2-degree squares. From tuna boat logbook data provided by the Inter-American Tropical Tuna Commission.

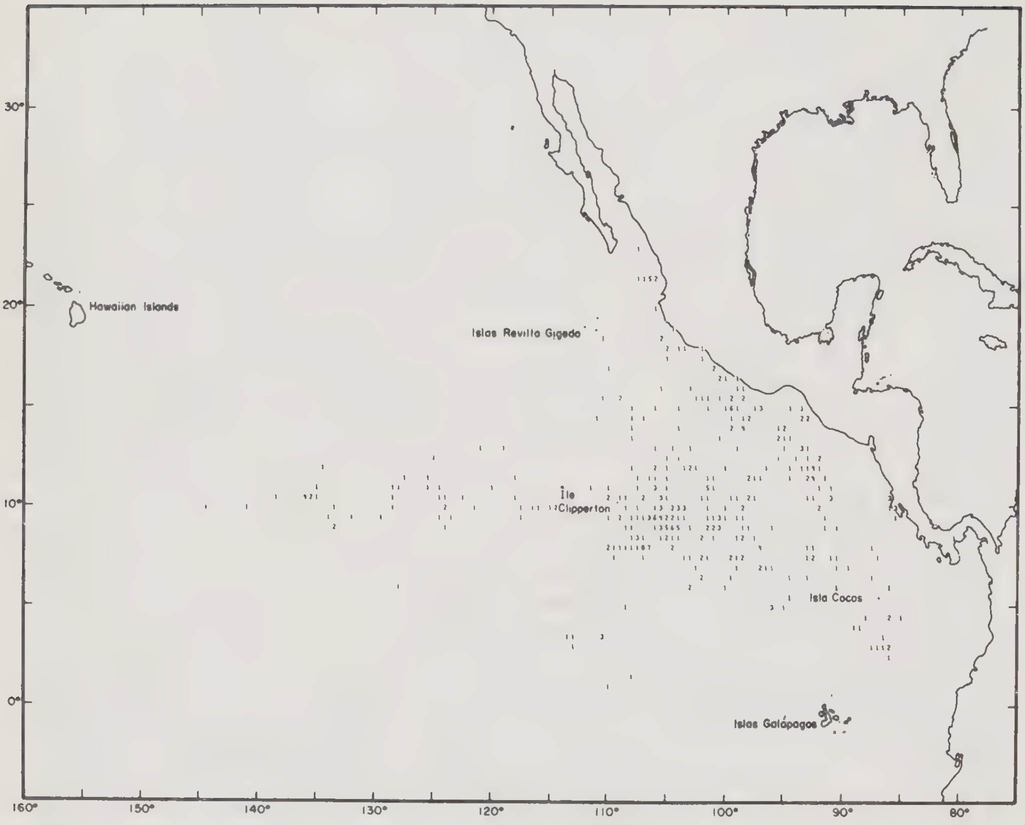

Figure 55. Distribution of records of spinner porpoise in the eastern tropical Pacific including collection localities of museum specimens, sightings from research vessels, and sightings by scientists aboard commercial fishing vessels. Numbers represent records per 1/2-degree square.

high and turned round not less than three times in the air, as if they had been on a spit" (from 1773 translation). This spinning behavior has been well described by Hester, Hunter, and Whitney (1963) and is exhibited in the wild only by "spinners" (*Stenella longirostris* sensu Hershkovitz, 1966), around the world (Tomich, 1969; Caldwell et al., 1971).

The taxonomy of the spinners is very confused, because all the holotypes involved are from unknown localities (save one, that of *Delphinus roseiventris,* from Malaysia), and because of much confusion by early workers of spinners with long-snouted species of *Delphinus.*

The skull of the spinner porpoise of the eastern Pacific (described below in section on variation), and of spinners from other parts of the world, has a long, attenuate rostrum (approximately four times as long as broad at the base), from 45 to 61 teeth in each row, very shallow palatal grooves, and very small posttemporal fossae (29-47 mm high; 7.2-11.8% CB length). These criteria are used below as background aids.

Gray in 1828 described *Delphinus longirostris,* on the basis of a skull of unknown provenance in the private museum of D. Brookes, as having "*Osse palatino carinato, postice convexo; rostro longissimo attenuato, supra depresso, lineâ mediâ elevatâ; dentibus parvis utrinque* $\frac{48 \quad 50}{48 \quad 50}$." He clearly differentiated it from *D. delphis* in having the "palate bone more strongly keeled." The specimen was not figured. In the same paper he described *D. capensis,* apparently from a stuffed or preserved whole animal from the Cape of Good Hope. The description includes no skeletal characters except a tooth count of "circiter $\frac{50}{50}$" and consists entirely of measurements and color notes obviously taken from a whole specimen. Although he stated that "this dolphin is at once distinguished by the shortness of his beak," he obviously meant "length," as the measurements and a figure of external appearance clearly indicate that a long-snouted animal is involved.

The Brookes collection was broken up in 1828 and in part purchased by the Leiden Museum. Schlegel (1841) described and figured under *Delphinus longirostris* a skull he said was used by Gray as the basis for *D. longirostris.* According to Flower (1884) the specimen was one of two purchased by the Leiden Museum and was listed in the original list of items purchased as "*Phocaena longirostris.*" The skull is evidently of a spinner, judging from the relatively flat palate, small cranium, long attenuate snout, very small posttemporal fossae, and high tooth count (55). This skull has been reexamined by many subsequent workers (Flower, 1883, and van Bree, 1971*b*, among others) and definitely does not have a palate "more strongly keeled" than that of *D. delphis* but, as noted by Schlegel himself (1841), it lacks palatal grooves. Schlegel (in Temminck and Schlegel, 1844) stated that the proper tooth count for the skull was 55, and that Gray had counted only 48-50 on each side because the anterior end of the cranium was mutilated and some teeth were missing. Gray was very explicit, however, about the carinated palate of *D. longirostris,* including it in the Latin description; one must conclude that the specimen sold to the Leiden Museum may not have been the type specimen used by Gray, but rather one belonging to a different species.

The Leiden Museum possessed several crania from the Cape of Good Hope "*absolument sembable à celui de la collection de Brookes*" (Temminck and Schlegel, 1844), and Schlegel for this reason synonymized Gray's *D. capensis* (described from external characters only) with *D. longirostris.* He did this in spite of the strong conflict between the description of *D. longirostris* and the nature of the purchased skull from the Brookes Museum. He also stated that the *D. longirostris* of Dussumier (in G. Cuvier, 1829) was also the same species. He referred a specimen from Japan to Gray's *D. longirostris* as well. Only a painting was collected of this specimen, and it obviously belonged to a species of *Delphinus* (sensu stricto) as noted by Takemura, Yoshida, and Mizue (1967).

The only thing clear emerging from this muddle in terms of original taxonomy is that *D. longirostris* Gray was described from a skull with strongly carinated palate and that the type specimen has probably been lost, the opinions of Schlegel and Flower notwithstanding. It must be noted that Gray in his subsequent works on Cetacea (1846, 1850, 1866*a*, 1866*c*, 1868*b*) retained *D. longirostris* Gray ("The Cape Dolphin") as a long-snouted species with deeply grooved palate and embraced the synonymy that Schlegel erected probably correctly but for the wrong reason. He did not include in the same section of *Delphinus* the species (*D. microps, stenorhynchus,* and *alope*) based on skulls from unknown localities and found by later workers to be similar to the Leiden specimen

(Flower, 1883) and from spinners, but placed them in a separate section *Clymene* (Gray, 1866*c*) with "Palate flat behind." It is evident that he assumed that Schlegel was correct in thinking that the Leiden Museum possessed the type of his *D. longirostris* and did not know that the specimen in question had a flat palate rather than a deeply grooved one.

The question of the fate of the holotype of *D. longirostris* Gray, 1828 will never be resolved satisfactorily. In view of this, it would seem best to designate the Leiden specimen as a lectotype of *D. longirostris* of Schlegel, 1841, and take Schlegel's figure and description as the earliest ascertainable starting point of the taxonomy of the spinners. This is the usage of Lütken (1889). It is also my usage here. As this strategy by implication resurrects *D. longirostris* Gray, 1828 as a species of *Delphinus* (sensu stricto), the trivial name *longirostris* may technically become unavailable for the spinners, and the next name applied to the species dealt with by Schlegel would have priority. Whether this would be *microps,* Gray, 1846, *alope* Gray, 1846, or *roseiventris* Wagner, 1846, would depend on the outcome of comparison of the holotypes with each other and with adequate series from around the world. Hershkovitz listed only one species of spinner, *S. longirostris* (Gray) including all the above names, but, aside from the problem discussed above, as van Bree (1971*b*) noted, this probably correct synonymy should be held in abeyance until the group is better known. The skeletons, color patterns, and external proportions of spinners from many parts of the world have not yet been adequately described. Another possible approach would be to conserve the long used name *longirostris* for the spinners, as *longirostris* Schlegel,1841, and suppress *longirostris* Gray, 1828 because of its uncertain status. Formal nomenclatural moves such as these must await more definitive knowledge of the spinners. The usage here is strictly provisional.

Gray (1850, 1866*a*) referred specimens from the "Coast of Brazils" and "near mouth of Rio de La Plata" to *D. microps.* He then (1866*c*) placed *microps, alope,* and *stenorhynchus* in *Clymene,* and subsequently (1868*a*) emended *Clymene* to *Clymenia,* giving the habitat of *C. alope* as Cape Horn.

Van Beneden and Gervais (1868-1880) placed *Clymenia* in their new genus *Prodelphinus.* Flower (1884), in line with his above-discussed views, placed *Clymenia stenorhyncha, microps,* and *alope* in a "section" (synonymy of ?) under *C. longirostris* (Gray). Later (1885), Flower recognized *Prodelphinus alope, microps,* and *longirostris,* but placed *D. stenorhynchus* in the synonymy of *P. longirostris.*

Lütken (1889) mistakenly referred specimens to *P. alope;* these were spotted porpoise.

True (1889) agreed with Flower's earlier (1884) conclusions regarding the synonymy of *P. longirostris* (Gray).

One hundred eighty-four years elapsed between publication of Pernetty's (1769) observations of what were probably spinners off West Africa and the first publication of a firm record of an Atlantic spinner. Moore (1953) referred to *Stenella longirostris* (Gray) a specimen harpooned in 1930 from a school "of several thousand" about 45 miles off Miami Beach, Florida. In recent years several additional records of spinners in the Atlantic have appeared.

Cadenat and Doutre (1958) reported on a specimen ("un *Prodelphinus*? indéterminé") from off Senegal that probably was a spinner, judging from the published photograph (triangular dorsal fin, thin light line from eye to posterior insertion of flipper, high cape with greatest development behind the dorsal fin). Unfortunately, the specimen was not saved. The tooth counts $(\frac{37 \mid 39}{42 \mid 42})$ are low for a spinner but were taken on the fresh specimen, and anterior teeth may have been embedded in the gums. The same authors later (1959) referred tentatively to *Prodelphinus longirostris* (Gray) four spinners from off Senegal (14°35′N, 17°48′W) that in coloration and body form were very similar to the eastern Pacific spinners. The skull of one of these specimens was figured by van Bree (1971*b*).

A large herd of spinners was stranded on a small island a few miles off the coast of Florida in the Gulf of Mexico in 1961. Layne (1965) compared the skull of one directly with the type of *S. longirostris* (Gray) and concluded that they were of the same species. These animals in shape and coloration were more like the Hawaiian spinner than the eastern Pacific or eastern Atlantic (as illustrated by Cadenat and Doutre) spinners. Caldwell et al. (1971) recorded occurrence of a "long-snouted or spinner dolphin belonging to the '*longirostris-roseiventris*' group of *Stenella*" from Saint Vincent in the Lesser Antilles and published a photograph of an animal that also strongly resembles the Hawaiian spinner in coloration, even to the dip in the ventral margin of the cape over the eye (see Perrin, 1972). Van Halewijn and van Bree (1972) reported a skull from Venezuela that they referred to *S. longirostris.*

The other, earlier records from the Atlantic, as of *D. microps* from "the coast of Brazil" by Gray, 1850, and from Rio de La Plata by Gray, 1866*a*, must be regarded as questionable, because of imprecise locality in the first instance and lack of substantiation by a specimen in the second.

Indian and Pacific Oceans

Dussumier painted watercolor sketches of several animals captured by him in 1828 and 1829. These excellent sketches remained unpublished until very recently (Arvy, 1972). Two of the specimens appear to have been spinners. One, a male, was captured on May 2, 1829 at 6°S and 85°E (about 600 miles southeast of Sri Lanka). The other, "female dolphin, no. 6," was caught "a few leagues to the east of the Maldive Islands, 73°E, on July 31, 1829." Specimens from Sri Lanka have been referred to *Stenella alope* (Gray) by Ellerman and Morrison-Scott (1951).

To the east, Hombron and Jacquinot in their atlas (1842-1853) of specimens collected during the voyage of the *Astrolabe* and *Zélée* illustrated the external appearance and skull (of the same individual?) of an animal they called "dauphin à ventre rose" from "la Mer des Molugues" (Jacquinot and Pucheran, in Hombron and Jacquinot, 1853). The color pattern shown is very similar to that of the adult Hawaiian spinner (Perrin, 1972), but the small size (1.18 m) indicates that the specimen may have been a calf. Wiegmann (in von Schreber and Wagner, 1846) published a figure (with no text) based on the plate of Hombron and Jacquinot and attached the name *Delphinus roseiventris.* Jacquinot and Pucheran (Hombron and Jacquinot, 1853) published an account of the specimen, with external measurements, and acknowledged Wagner as the author of the species. Van Beneden and Gervais (1880) placed the species in their new genus *Prodelphinus* and illustrated the skull of the holotype (?)—the skull figured by Jacquinot and Pucheran in the Paris Museum. Flower (1884) stated (that the Paris skull) "except in its smaller size, closely resembles the original *longirostris* of Gray. It is certainly the same as *microps*

[Gray, 1846]." Lütken (1889) placed the species in the synonymy of *Prodelphinus longirostris* (Schlegel). True (1889) disagreed with this view, preferring to "leave [*Delphinus roseiventris*] in the genus to which it was originally assigned, as distinct from *longirostris, microps, alope,* and *stenorhynchus*" which he considered to belong to a single species in *Prodelphinus.* Iredale and Troughton (1934) erected the new genus *Frettidelphis* for *D. roseiventris* Wagner, a dubious contribution that has generally been ignored. Rice and Scheffer (1968) tentatively recognized two species of spinners, "*Stenella longirostris* Gray, 1828 [sic] and *Stenella roseiventris* Wagner, 1853 [sic]." They stated that the "two forms differ markedly in body form and color pattern," but in point of fact the external appearance of spinners of the population from which the holytype of *S. longirostris* came can only be guessed at, since the type was a skull from an unknown locality. Of the holotypes, only that of *roseiventris* is of known external appearance, which is of little use because the specimen may have been a calf. Coloration changes during development (Perrin, 1972). Specimens have been referred to *longirostris* and *roseiventris* on a rather willy-nilly basis (see below), and there exists in the literature no valid justification for separating the species on the basis of coloration. As with the spotted porpoises, the definitive taxonomic and nomenclatural decisions must be based on large series of specimens from precisely known localities, with correlated data on external appearance and proportions.

According to True (1889), the specimen of *P. longirostris* described by Lütken (1889) was "from Australia," and very recently a specimen was collected in Queensland (G. Heinsohn, personal communication).

Spinners occur in Japanese waters. Aoki (1913) listed *Prodelphinus longirostris* (Gray) from Japan ("Madara iruka"), but was referring to the record published by Temminck and Schlegel (1844), which was of a species of *Delphinus* (sensu stricto). Ogawa (1932) referred a specimen to *Delphinus roseiventris,* but the accompanying photograph shows what appears to have been a young spotted porpoise. The first real record of a spinner from Japan was that of Ogawa (1936) of a specimen from Nagasaki that he referred to *Prodelphinus longirostris* (Gray). The clear photographs of the head show an animal with visible color pattern like that of the Hawaiian spinner and the spinner of the western Pacific, Caribbean, and Gulf of Mexico, but unlike that of the spinners of the far eastern Pacific (see Perrin, 1972). Kuroda (1952, fide Nishiwaki, 1972) described a subspecies *Stenella longirostris kunitomoi* based on a specimen collected off Nagasaki. He stated (fide Nishiwaki) "that this subspecies differs from the holotype [of *S. longirostris*] by lacking fine spots." This argument is specious for the reasons discussed above re the statement of Rice and Scheffer (1968). Mizue, Yoshida, and Sonoda (1964) reported on four specimens from near Goto [Island] in Nagasaki [Prefecture]. According to them, the Japanese name of this animal is "*Hashinaga iruka*," as opposed to "*Madara iruka*" (spotted porpoise) and "*Ma iruka*" (*Delphinus* sp.). They disagreed with Ogawa's choice of *Prodelphinus longirostris,* concluding that the skulls and vertebral counts were sufficiently different to justify considering them to belong to an undescribed species. Van Bree (1971*b*) disagreed, tentatively referring the specimens to *S. longirostris* (Gray, 1828). The color pattern as illustrated again is in every respect like that of the Hawaiian and Atlantic spinners, as is the shape of the dorsal fin.

The Hawaiian spinner has been variously identified: as *Stenella roseiventris* (Wagner) by Fraser, according to Morris and Mowbray, 1966; as *Stenella* cf. *roseiventris* (Wagner) by Brown, Caldwell, and Caldwell, 1966; and as *Stenella longirostris* by Nishiwaki, 1967, and by Tomich, 1969.

I have discussed above the distribution and taxonomic history of spinners in the eastern Pacific, where they have been referred variously to *S. microps* (Gray 1846) and *S. longirostris* (Gray 1828).

There exist, then, populations of spinners in tropical waters of the eastern Pacific, Hawaii, western Pacific, Indian Ocean, eastern Atlantic, and western Atlantic, with an unknown degree of continuity between them. The several holotypes are all from unknown localities, except that of the juvenile *roseiventris* from Malaysia, and were of unknown adult coloration and external proportions.

VARIATION

Coloration

I have previously described development and variation of the color patterns of the eastern Pacific and Hawaiian spinner porpoise (Perrin, 1972). Ontogenetic change is less drastic than in the spotted porpoise, which begin life unspotted, but geographical variation is much more pronounced (fig. 26 in Perrin, 1972). The patterns can be analyzed in terms of discrete component systems, and most geographical variation appears to be in a "dorsal field system" overlying a basic general pattern. The overlay is darkest and most extensive in the easternmost form considered and lightest and least extensive in the Hawaiian form. I defined the geographical variants "eastern" and "whitebelly" on the basis of coloration and external morphology (Perrin, 1972), and a third eastern Pacific form, "Costa Rican" is defined below on the basis of skull morphology (section on skeletons).

The only available data concerning the external appearance of the Costa Rican animal are underwater photographs in the possession of Scott MacVay (personal communication) of several very slim, long-snouted animals encountered off San Salvador, El Salvador. What can be seen of the color pattern appears to be similar to that of the "eastern spinner" (Perrin, 1972), except that no genital or axillary light areas can be seen, a possible artifact of the lighting. The cape (terminology of Perrin, 1972) is very faintly apparent in some of the photographs.

The color patterns of the whitebelly and Hawaiian spinners are very similar (Perrin, 1972). The main difference between them is that the whitebelly spinner distinctively has the ventral margin of the overlay (the lateral dark field) not entire, but speckled. Also, in the Hawaiian spinner, there is a dip in the ventral margin of the cape over the eye, a feature not present in the whitebelly form. The color pattern of the whitebelly spinner is the more variable of the two; some individuals are much more like the Hawaiian type than others. The differences between the two forms are most pronounced in large adults.

External Morphology

No data other than total lengths have previously been published on the external proportions of spinner porpoise from the eastern Pacific or Hawaii. Published measurements of total length (Harrison, Boice, and Brownell, 1969*b*; Pilson and Waller, 1970; Perrin, 1972) range from 75 to 186 cm. In this section I present the results of investigations of morphometrics of large series of spinners from the tuna fishery and compare them with data for Hawaiian spinners.

The same external measurements were made as for the spotted porpoise (fig. 1 & 2). Some difficulty was encountered in obtaining repeatable measurements of height of dorsal fin, because in large males the fin is canted forward (see below); hence, that measurement was dropped from consideration. For some specimens (11), only total body length and depth of body at center of ventral hump were measured.

Development

The spinner porpoise differs from the spotted porpoise in ontogeny. The sample of measurements for analysis of ontogeny (and sexual dimorphism, described below) included 120 postnatal specimens and 21 fetuses from the tuna fishery.

Most of the lengthwise measurements of the anterior portion of the body exhibit the same pattern of growth as in the spotted porpoise: their relationship with total length is linear until total length reaches approximately 1500 mm, after which they increase much less rapidly, if at all, and vary markedly.

The pattern of change in the proportional dimensions of the appendages is, however, quite different from that of the spotted porpoise. The flippers continue to increase in length (fig. 56f) and width (fig. 56g) after puberty at an increased rate relative to increase in total length. The curve for flipper width, instead of leveling off at 1500 mm, turns slightly upward. Even more striking is the pattern of increase in fluke span (fig. 56h). The curve for the spotted porpoise (fig. 10d) is linear, but for the spinner it takes a sharp upturn at puberty. A possible explanation of this difference is that the absolute rate of growth (relative to time) of fluke span (and flipper length and width) is similar in both species, but that the spotted porpoise continues to grow in total length longer than the spinner after puberty (it does reach a greater size), causing a differential relationship between appendage size and total length in adult animals. Whatever the cause, the result is that adult spinners have proportionately larger appendages than do adult spotted porpoises (see section below on variation in adults).

A sexual difference exists in the pattern of increase of the snout to dorsal fin tip measurement and girth at the anus, resulting in sexual dimorphism in the adult (discussed below).

After completion of the analyses of development based on measurements relative to total length, the dentinal layers in the teeth of a subsample of the specimens were examined. The teeth were prepared as for the spotted porpoise. As demonstrated by plots for selected measurements (fig. 57), the results confirm the conclusions reached in the preceding analysis. Especially striking is the contrast between the spotted porpoise and

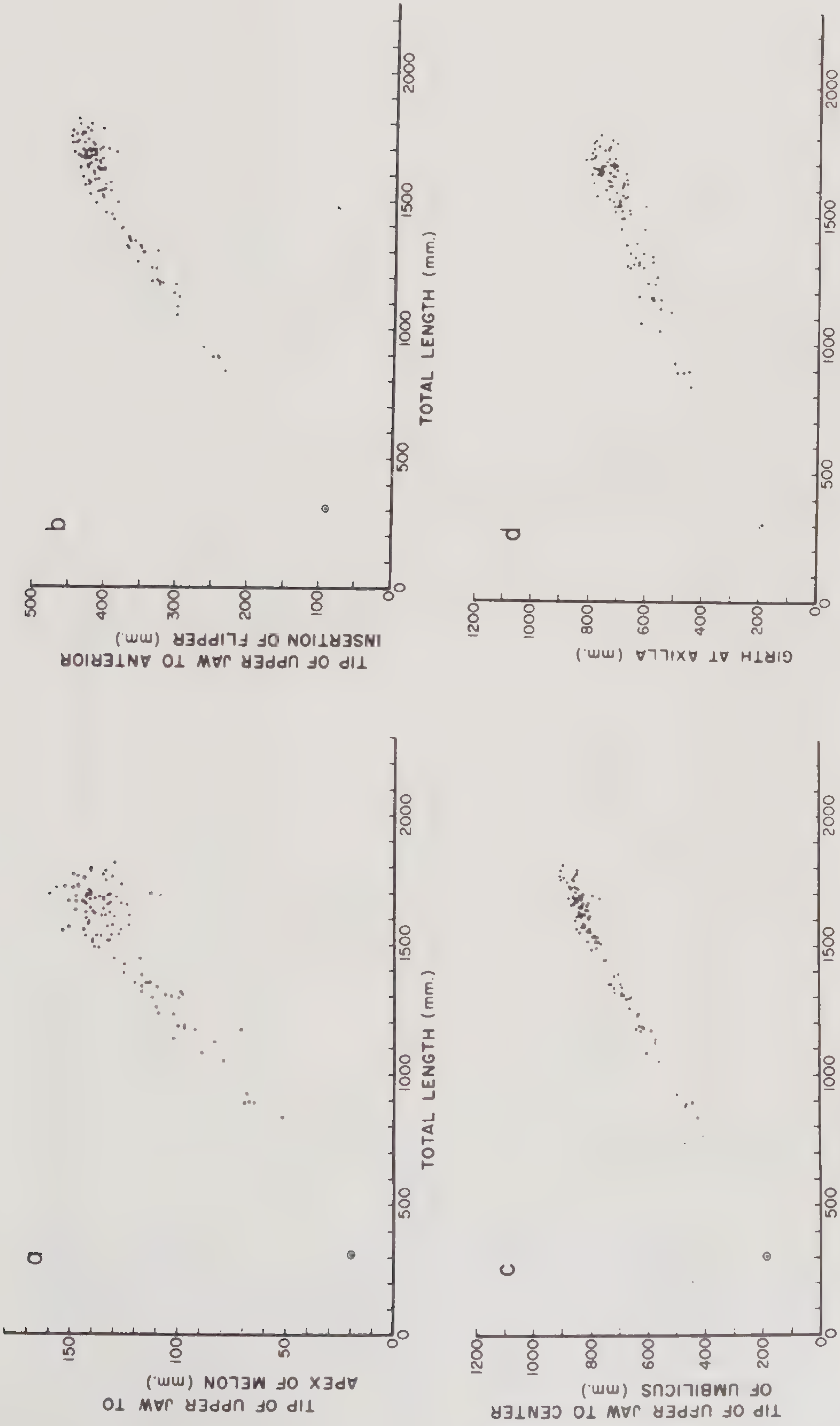

Figure 56. External development of spinner porpoise: scatterplots of external measurements on total length, demonstrating changing proportions (continued).

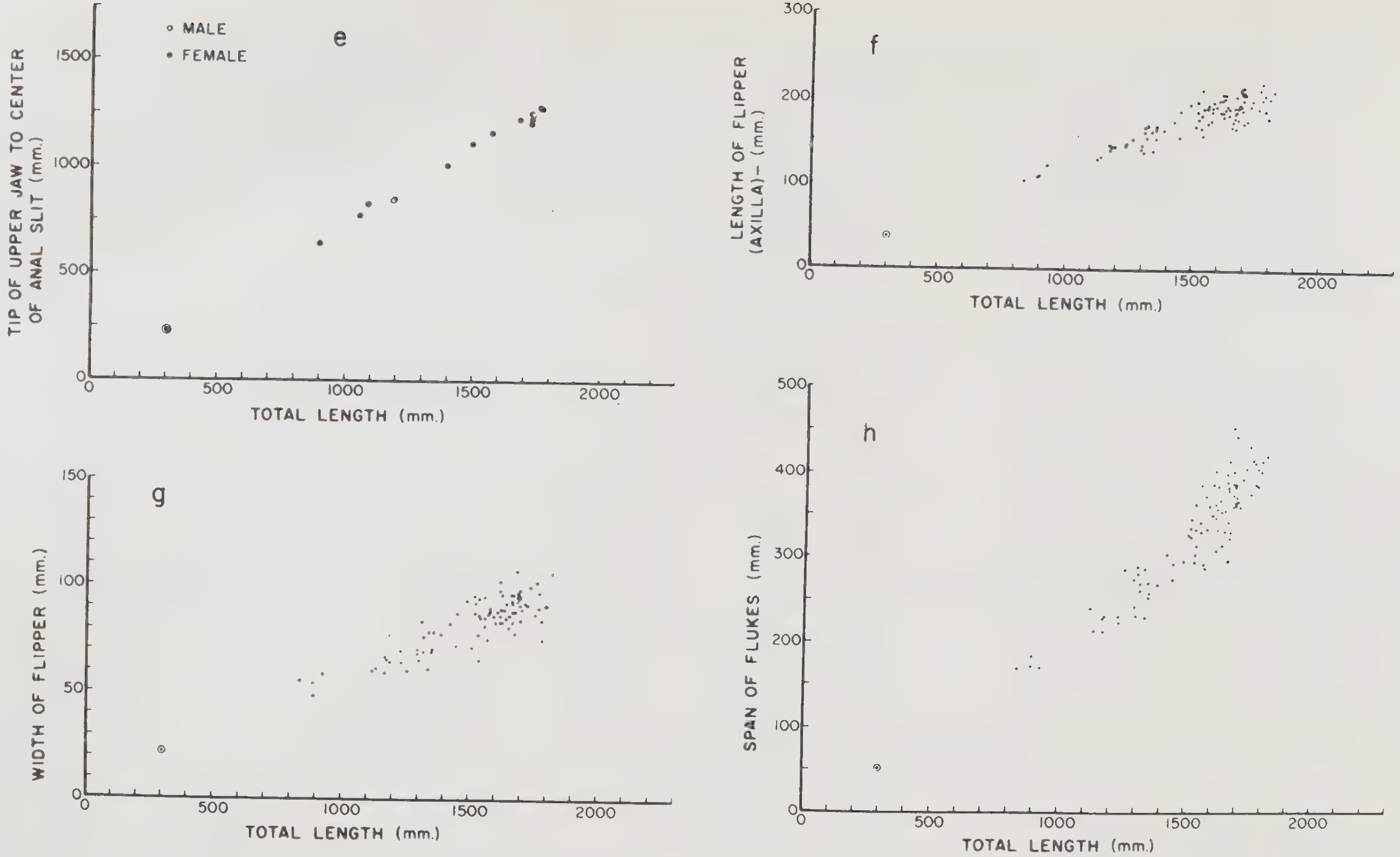

Figure 56 (continued). External development of spinner porpoise: scatterplots of external measurements on total length, demonstrating changing proportions.

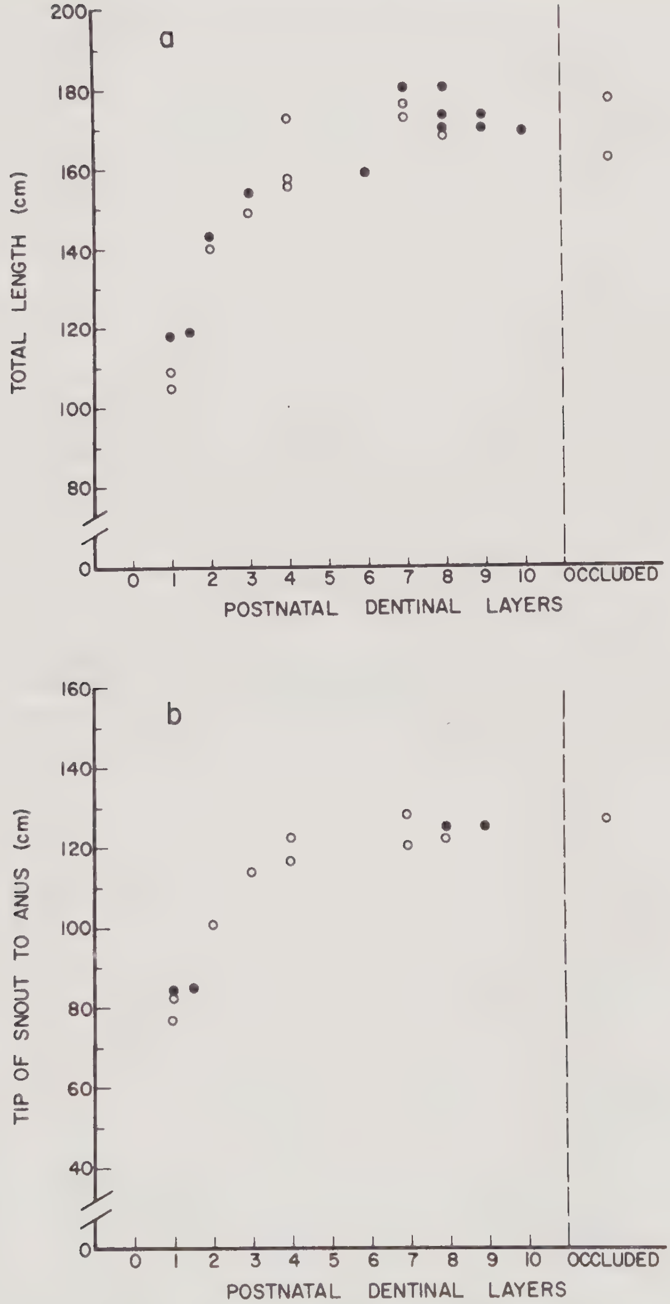

Figure 57. External development of spinner porpoise: scatterplots of external measurements on number of postnatal dentinal layers. Solid symbols are males, open symbols are females (continued).

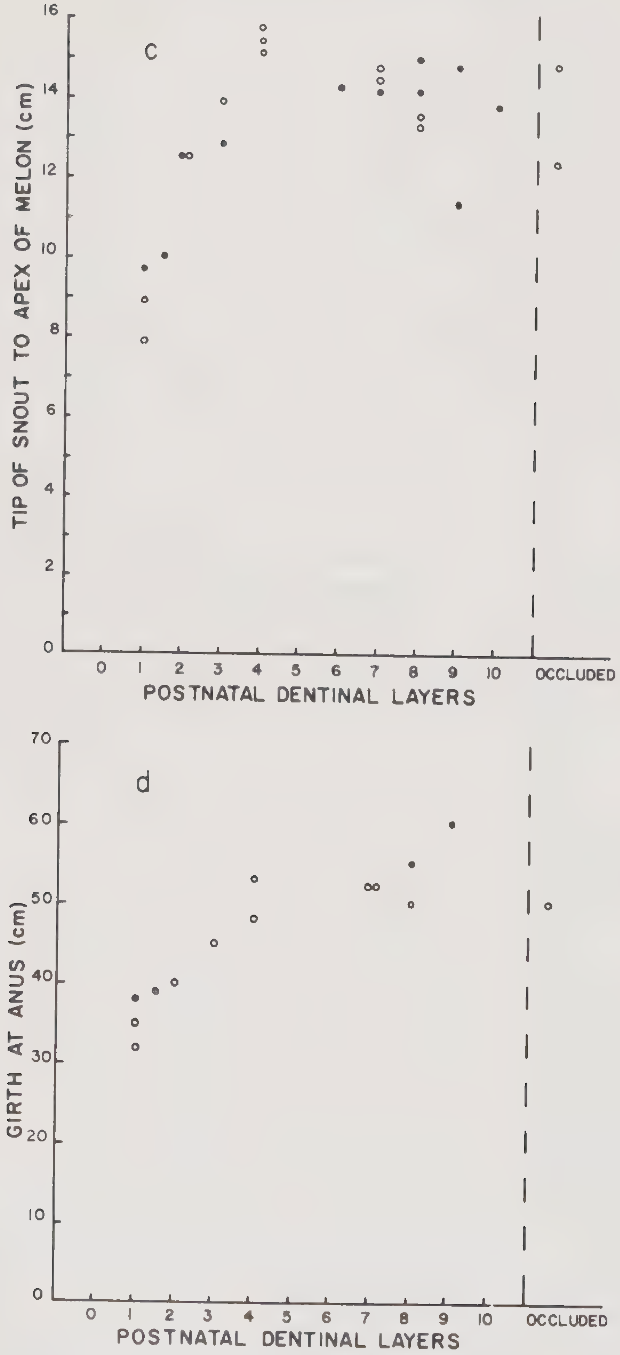

Figure 57 (continued). External development of spinner porpoise: scatterplots of external measurements on number of postnatal dentinal layers. Solid symbols are males, open symbols are females.

the spinner in the pattern of relation between dentinal numbers and total length. The curve for the spinner (fig. 57a) flattens off after about 5 or 6 layers, whereas the curve for the spotted porpoise continues to rise until at least 12 layers are reached. The contrast appears to be paralleled in the snout-to-anus measurements (figs. 11b and 57b). Snout length (figs. 11c and 57c), however, seems to show in the two forms a similar pattern of leveling off at puberty.

Sexual Dimorphism

Dimorphism exists in adults. Sexual maturity was determined by examination of gonads. The ovaries of 13 of 16 female spinners over 1600 mm in total length contained at least one corpus (corpus albicantium or corpus luteum). Ten of 11 males longer than 1625 mm were sexually mature (histologically showed spermatogenesis). These two breaking points were used to define adulthood for purposes of this analysis. Adults are defined as females longer than 1600 mm and males longer than 1625 mm.

Females have longer snouts, both absolutely (table 15) and relatively. This is also reflected in the other anterior measurements containing the snout.

The dorsal fins of adult male spinners in the eastern Pacific cant forward to varying degree (fig. 58), and the greater snout-to-dorsal-fin measurements for females reflects this feature. In some individuals the fin gives the impression of being reversed. Also evident in adult males is a more or less well-developed ventral keeled hump composed of connective tissue (see figures in Perrin, 1972). The two features are correlated in their development and are highly variable in their sexual dimorphism (figs. 58 and 59). The

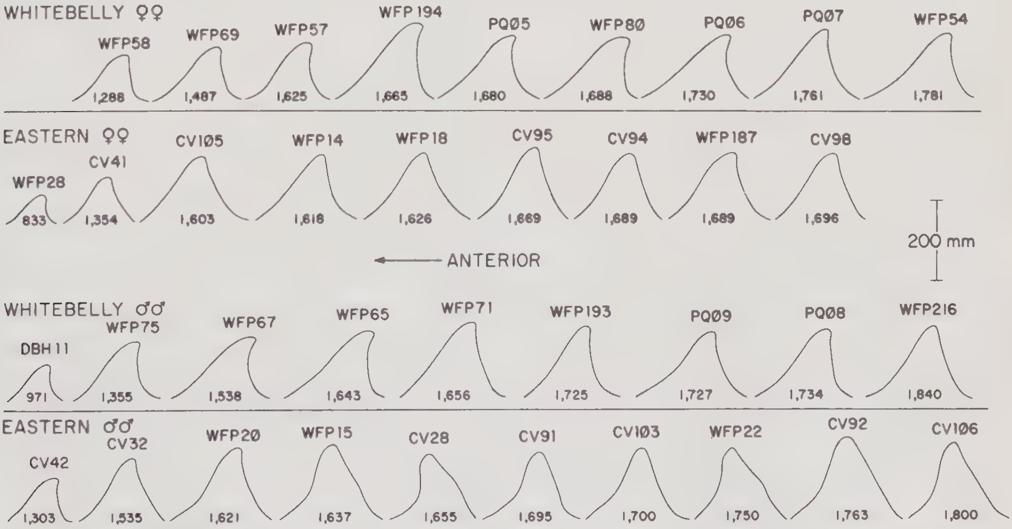
WHITEBELLY ♀♀
WFP58
1,288
WFP69
1,487
WFP57
1,625
WFP194
1,665
PQ05
1,680
WFP80
1,688
PQ06
1,730
PQ07
1,761
WFP54
1,781
EASTERN ♀♀
WFP28
833
CV41
1,354
CV105
1,603
WFP14
1,618
WFP18
1,626
CV95
1,669
CV94
1,689
WFP187
1,689
CV98
1,696
200 mm
ANTERIOR
WHITEBELLY ♂♂
DBH11
971
WFP75
1,355
WFP67
1,538
WFP65
1,643
WFP71
1,656
WFP193
1,725
PQ09
1,727
PQ08
1,734
WFP216
1,840
EASTERN ♂♂
CV42
1,303
CV32
1,535
WFP20
1,621
WFP15
1,637
CV28
1,655
CV91
1,695
CV103
1,700
WFP22
1,750
CV92
1,763
CV106
1,800

Figure 58. Developmental, sexual, individual, and geographical variation in size and shape of dorsal fin of spinner porpoise. Drawings from tracings of fins. Numbers above fins are field numbers. Total lengths in mm below fins.

Table 15. External measurements of adult male and female spinner porpoise, with statistical comparison of means

Measurements	Number of specimens	Males				Number of specimens	Females				Absolute value of significant t[c]
		Range (mm)	Mean (mm)	Standard deviation (mm)	CV (100 s/x̄)		Range (mm)	Mean (mm)	Standard deviation (mm)	CV (100 s/x̄)	
Total length	24[a]	1628-1818	1717	54.7	3.19	29[a]	1603-1830	1683	50.2	2.98	2.36
Tip of upper jaw to center of eye	24[a]	277-322	305	9.9	3.24	29[a]	287-325	308	9.6	3.12	
Tip of upper jaw to apex of melon	24[a]	113-149	136	8.4	6.18	29[a]	123-160	142	8.2	5.77	2.62
Length of gape	24[a]	237-276	265	9.1	3.43	29[a]	252-283	268	9.4	3.51	
Center of eye to center of blowhole	24[a]	109-124	116	3.5	3.02	29[a]	105-129	116	5.8	5.00	
Tip of upper jaw to blowhole	24[a]	277-319	305	9.3	3.05	28[a]	287-327	309	11.4	3.69	
Tip of jaw to anterior insertion of flipper	24[a]	392-455	431	16.5	3.83	29[a]	408-451	429	11.7	2.73	
Tip of upper jaw to tip of dorsal fin	24[a]	867-1050	948	37.6	3.97	29[a]	892-1058	973	40.6	4.17	2.31
Tip of upper jaw to midpoint of umbilicus	24[a]	760-902	848	31.4	3.70	29[a]	801-897	836	24.0	2.87	
Girth at axilla	24[a]	679-805	764	34.6	4.53	29[a]	679-821	737	32.3	4.38	2.93
Length of flipper, axilla to tip	21[b]	168-220	195	13.5	6.92	23[b]	167-215	194	13.2	6.80	
Width of flipper	21[b]	81-107	94	7.0	7.45	23[b]	75-102	89	6.2	6.97	2.51
Span of flukes	22[b]	314-453	391	36.3	9.28	24[b]	296-414	365	25.1	6.88	2.85

[a] Includes specimens from all collections.

[b] Frozen specimens not included.

[c] For comparison of means, Student's t was computed, after an F-test for homogeneity of variance at $\alpha = .05$.

Table 16. External measurements of Costa Rican, eastern, whitebelly, and Hawaiian spinner porpoise, with statistical comparison of eastern and whitebelly means

		Costa Rican		Eastern					Whitebelly					Hawaiian		Eastern vs. whitebelly: absolute value of significant t at α = .05 between eastern and whitebelly
		Sample size	Range (mm)	Sample size	Range (mm)	Mean (mm)	Standard deviation (mm)	CV	Sample size	Range (mm)	Mean (mm)	Standard deviation (mm)	CV	Sample size	Range (mm)	
Total length	(M)	2	1814-2164	24	1628-1818	1717	55.2	3.21	10	1643-1840	1730	58.8	3.40	2	1789-1854	—
	(F)	3	1963-2033	30	1610-1786	1681	47.2	2.81	11	1625-1781	1723	53.6	3.11	3	1720-2007	2.44
Tip of snout to center of eye		4	320-351	54	264-309	292	9.6	3.29	21	265-309	295	11.8	4.00	6	318-350	—
Tip of snout to apex of melon	(M)	2	143-158	24	112-153	134	8.8	6.57	10	136-148	142	5.1	3.59	2	174-178	2.68
	(F)	2	158-168	30	122-161	142	9.0	6.34	10	134-157	148	6.9	4.66	3	178-191	—
Length of gape		4	283-305	54	225-269	254	9.1	3.58	21	230-276	257	10.6	4.12	5	300-311	—
Tip of snout to blowhole		4	311-360	53	265-313	294	10.5	3.57	21	266-310	294	10.3	3.50	6	315-381	—
Tip of snout to anterior insertion of flipper		4	445-472	54	367-426	401	12.2	3.04	21	388-439	413	13.6	3.29	4	420-502	3.70
Tip of snout to tip of dorsal fin	(M)	2	954-1000	24	825-947	898	32.7	3.64	10	917-1014	954	31.9	3.34	1	1047	4.58
	(F)	3	948-1006	29	848-1005	923	36.4	3.94	11	908-1006	959	30.1	3.14	2	1030-1168	2.92
Tip of snout to umbilicus		5	930-966	54	750-890	828	26.5	3.20	21	787-895	846	31.7	3.75	5	870-1010	2.50
Girth at axilla	(M)	2	692-719	24	679-800	764	33.2	4.35	10	752-818	783	23.3	2.98	1	857	—
	(F)	2	735-771	30	679-794	736	29.3	3.98	11	755-868	796	38.4	4.82	2	787-813	5.34
Flipper length to axilla		5	158-174	50	167-220	195	12.6	6.46	15	175-208	192	9.4	4.90	6	190-248	—
Fluke span	(M)	2	399-402	24	314-453	391	34.8	8.90	7	334-442	396	34.2	8.64	2	394-400	—
	(F)	2	381-442	28	296-444	368	28.0	7.61	8	323-410	379	26.7	7.04	3	380-425	—

Table 17. Skeleton measurements and meristics differing between adult male and female spinner porpoise, with statistical comparisons of means

Variable	Unit	Males				Females						Absolute value of significant t, at $\alpha = .05$		
		Number of specimens	Range	Mean	Standard deviation	CV	Number of specimens	Range	Mean	Standard deviation	CV	Absolute measurements	Expressed as percentage of condylobasal length	Expressed as percentage of parietal width
1. Condylobasal length	mm	25	351-419	387.0	15.15	3.92	17	369-412	394.0	11.64	2.95			2.33
2. Rostrum length	mm	25	218-271	244.8	11.93	4.88	17	230-265	250.9	9.48	3.78			2.37
5. Rostrum width at mid-length	mm	24	38-47	42.7	2.39	5.59	16	37-46	41.1	2.64	6.31		2.19	
7. Rostrum width at 3/4 length	mm	24	27-36	32.0	2.46	7.69	16	27-35	30.3	2.62	8.66		2.63	
9. Rostrum tip to internal nares	mm	25	257-307	284.2	12.54	4.41	17	275-310	292.4	10.15	3.47		2.74	2.71
29. Occipital overhang	mm	26	0-11	4.7	3.17	68.21	21	3-12	6.8	2.81	41.54		2.08	2.51
44. Thyrohyal width	mm	16	15-23	17.4	2.03	11.68	20	13-22	17.7	2.21	12.50		2.31	
59. Axis lateral process length	mm	7	16-20	17.7	1.25	7.08	7	17-22	19.6	1.72	8.78	2.36		
69. First thoracic neural spine length	mm	7	12-22	17.3	4.31	24.93	7	17-28	23.6	4.08	17.29	2.81		

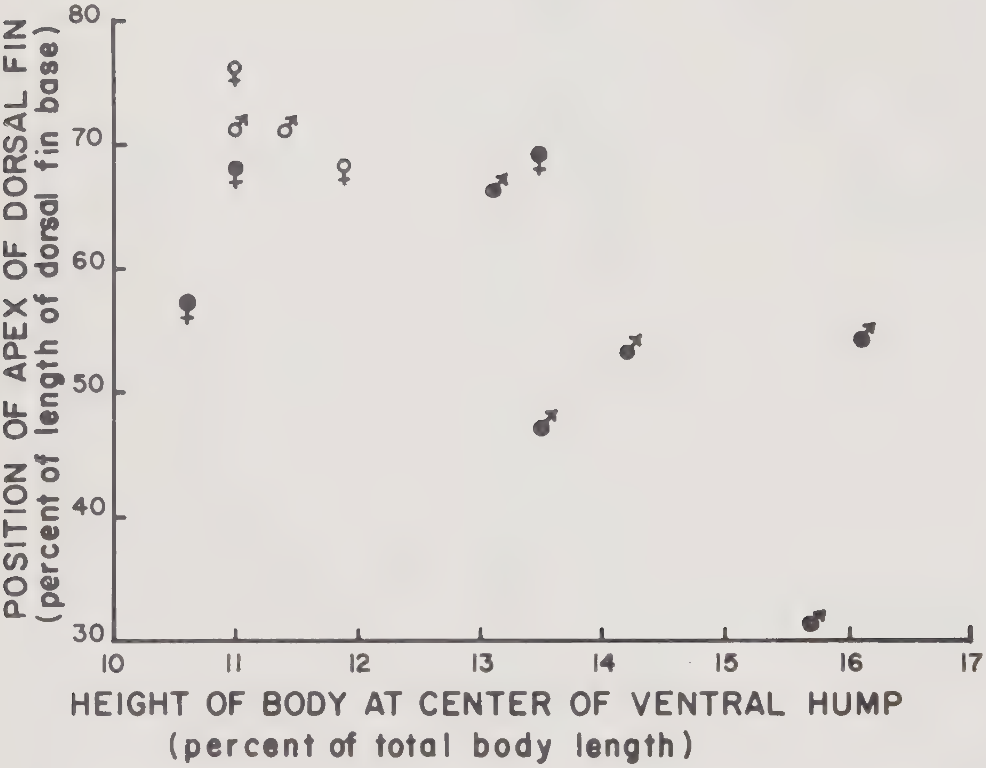

Figure 59. Relationship between forward cant of dorsal fin and development of ventral hump in spinner porpoise. Blackened symbols represent sexually mature specimens.

correlated features show great variation in degree of development. The possible functional significance of this sexually and geographically varying character complex as a species recognition signal in a mixed school has been discussed in another paper (Perrin, 1972).

Males exceed females in girth, width of flipper, and span of flakes (table 15), but these measurements are not different in males and females when taken as percentage of total length.

Individual Variation

In the spinner porpoise, as in the spotted porpoise, both males and females vary anteriorly most in the measurement of snout length (tip of upper jaw to apex of melon). This is indicated by the coefficients of variability for both the absolute measurements and the measurements expressed as percentage of total length. Also as for the spotted porpoise, the most variable measurements are the dimensions of the appendages: length and width of flipper and span of flukes. Individual variation in shape and size of the dorsal fin is great (fig. 58).

Geographical Variation

The spinner varies a great deal geographically. External measurements (table 16) are available for 4 adult "Costa Rican" spinners (unpublished data provided by David Waller) and 6 Hawaiian spinners (unpublished data provided by Robert L. Brownell, Jr., and Dale W. Rice: specimens "Momona" (name used at Sea Life Park) SLP-02-66 female, "Maka" female, OI-70-35 immature male, "Haina" sex unknown, "Opihi" male, MMBL 1194 female). In addition to the samples of measurements of 53 "adult" (males ⩾ 1625 mm, females ⩾ 1600 mm) mostly "eastern" spinners used in the above analyses of dimorphism, individual variation, and variation among schools, I have subsequently collected measurements of an additional 22 animals, for a total of 54 eastern and 21 whitebelly spinner specimens (fig. 60).

The four Costa Rican animals were very long. Both females were longer than any of the 30 eastern and 11 whitebelly females examined, and one male was longer than any

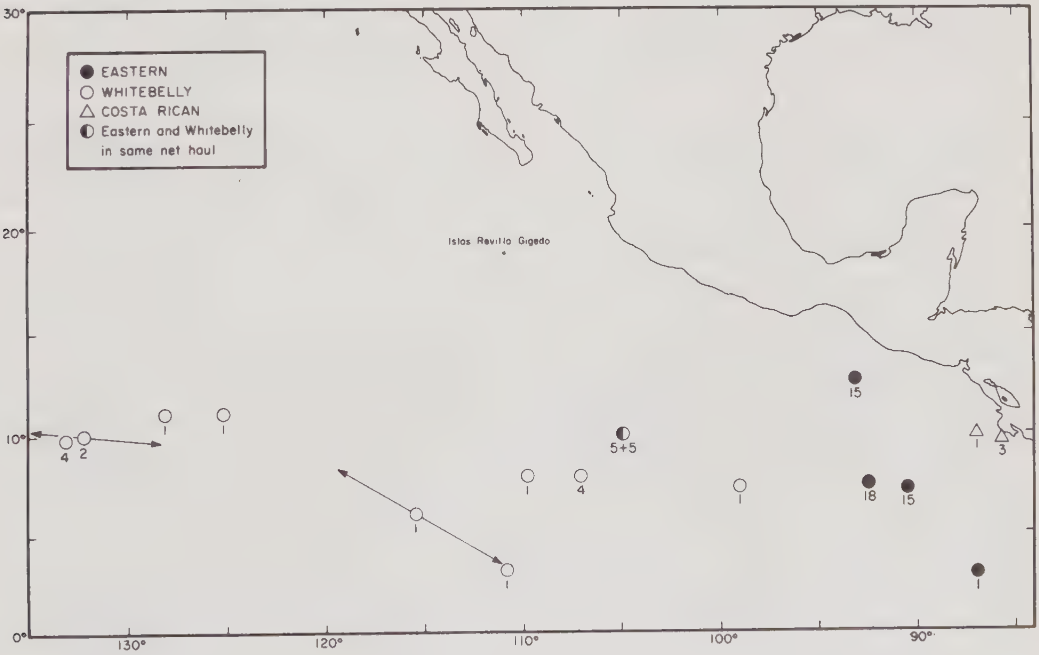

Figure 60. Provenance of 79 eastern Pacific specimens used in analysis of geographical variation in external proportions of spinner porpoise. The analysis also included specimens from Hawaii (see text).

of the 24 eastern and 10 whitebelly males. All four exceeded all the eastern and whitebelly spinners in the measurements tip of snout to center of eye, length of gape, tip of snout to anterior insertion of flipper, and tip of snout to umbilicus; and the overlap in other anterior and torso length measurements was slight. In flipper length, however, the overlap is extensive, and in fluke span and girth at the axilla the ranges for the Costa Rican series are entirely contained within the ranges for the eastern series. The resulting differences in proportions are striking. The Costa Rican animals were very slender; all four are below the ranges for the eastern and whitebelly series in proportionate girth. The same is true for proportionate length of flipper, although this may reflect a difference in measuring method. The mean value for proportionate fluke span is lower than for the other series, but the overlap is considerable. The dorsal fin tip is more anteriorly placed (or the postdorsal fin portion of the torso is proportionately longer) in both Costa Rican females than in any of the eastern or whitebelly females. The overall extreme slenderness of the Costa Rican animals is also apparent in the above mentioned underwater photographs of the spinners off San Salvador.

The whitebelly series differed from the eastern series in several measurements. The whitebelly females were on the average longest, the males had the longest snouts (consistent with the findings for length of the cranial rostrum), the measurements Tip of snout to tip of dorsal fin, and Tip of snout to umbilicus were greatest for both males and females, and girth at the axilla was greatest for females. When the measurements are considered in relation to total length, all but two of these differences disappear. The male whitebelly spinner on the average has the greatest proportionate girth at the axilla (fig. 61) and proportionately the greatest snout to dorsal fin tip distance, which reflects the greater forward cant of the fin in the male eastern spinner (fig. 58).

Adults of the Hawaiian spinner appear to be larger than whitebelly adults. The skull of MMBL 1194 (female, 172 cm) is of adult configuration (premaxillaries and maxillaries fused distally), but that of "Opihi" (male, 185 cm) is definitely of a subadult. OI-70-35 (male, 179 cm) was sexually immature (testes examined). The skulls of "Momona" (female, 201 cm), "Maka" (female, 183 cm), and "Haina" (sex unknown, 186 cm) are of adults. The three known females, (172-201 cm) were adults, but both males (179 and 185 cm) were subadults. This compares to ranges for whitebelly adults of 163-178 cm for females and 164-184 cm for males. The largest whitebelly male (of 10 measured) was smaller than one of the two Hawaiian subadults. The small sample (3) of Hawaiian animals known to be adult does not allow statistical comparison with the whitebelly series. Some differences are very clear-cut nonetheless. The greatest differences are in the anterior measurements, in particular the length of the snout. All the Hawaiian specimens, including the two subadult males, were greater than the whitebelly specimens in the distances tip of snout to eye, to melon, to angle of gape, to blowhole, and to flipper. There was overlap of the series in the long measurements to dorsal fin and umbilicus and in girth, but the Hawaiian specimens averaged larger. In flipper length and fluke span the overlap was nearly complete. When the measurements are considered as percentage of total length, the series are completely separated only in snout length (tip of snout to apex of melon). In summary, based on the few data available, the Hawaiian spinner is on the average longer than the whitebelly spinner and has a longer snout (more than 17 cm); the whitebelly spinner has a snout less than 16 cm long.

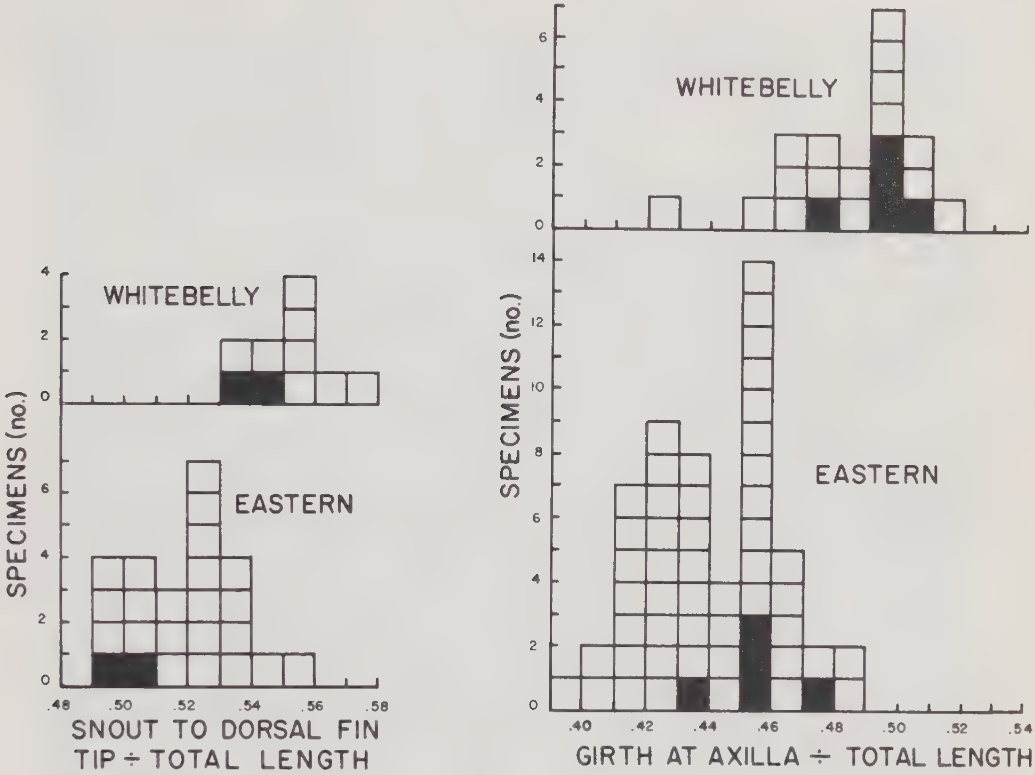

Figure 61. Geographical variation in (left) relative snout-dorsal fin length and (right) relative girth of spinner porpoise. Shaded squares represent specimens taken in a single net set and classified on basis of color pattern.

The dorsal fin of the Hawaiian spinner, while high and erect in large adult males, is always at least slightly falcate, but the fin of the whitebelly spinner ranges from slightly falcate in young animals and females to triangular in adult males, approaching the forward-canted fin of many large male eastern spinners (above, and Perrin, 1972).

Skeleton

No information on the skeletons of spinner porpoise from the eastern Pacific has previously been published.

Development

This account is based on 28 specimens: 16 eastern spinners collected in the tuna fishery aboard M/V *Carol Virginia* in 1968, 8 whitebelley spinners collected in the fishery aboard M/V *Pacific Queen* in 1969, and three small specimens (external appearance unknown) also from the fishery (LACM no. 27430, 27432, and 27433). Attention is given only to aspects of development in which this animal differs from the spotted porpoise. Additional available material from nearshore areas and from imprecisely known localities was not included. The series of 28 specimens comprises the following categories:

Class I.	Two newborn individuals, with no postnatal layers in the dentine (CB lengths 98 and 105 mm)
Class II.	Six calves, with one dentinal layer (CB length 121 to 128 mm)
Class III.	Six subadults, with 2 to 6 dentinal layers (CB length 134 to 145 mm)
Class IV.	Fourteen sexually mature adults, with 4 to >10 dentinal layers (CB length 133 to 149 mm). Of these, seven are complete skeletons and make up a subsample for which degree of physical maturity can be determined. Of the seven, five (with 7 to >10 dentinal layers, CB length 139 to 146 mm) are physically mature.

Note that these categories differ from those erected above for the spotted porpoise; they reflect the available material.

Cranial skeleton

The developmental series of crania of the spinner porpoise is shown in figure 62.

Braincase. Fusion of the interparietal with the supraoccipital appears to proceed more rapidly in the spinner than in the spotted porpoise. Fusion in one of the skulls with no postnatal layers has proceeded as far as in specimens of the spotted porpoise with 1 layer (Class II.5 in discussion of spotted porpoise). The telescoping process, however, does not seem to be accelerated. Proportions and relationships of the bones of the dorsal cranium are about the same in both species in specimens of presumed similar age. Closure of remaining occipital sutures is also affected. Of 17 specimens with 4 or more dentinal layers, in only 1 (with 5 layers) was any vestige of the parietooccipital sutural system visible outside the posttemporal fossa, whereas in the series of specimens of spotted porpoise examined such vestiges were common even among the oldest specimens.

The small, apparently nonfunctional foramina present in the occipital region of many specimens of spotted porpoise are not as common in the spinner series. Only one example was encountered in the 27 specimens, in an individual with 1 dentinal layer.

Growth of the cranium is not as protracted as it is in the spotted porpoise (fig. 63). It appears to cease after attainment of the adult plateau, when 3-4 layers have been laid down in the dentine.

Feeding apparatus. At birth the premaxillaries are in contact for approximately half the distance from the prenarial triangle to the tip of the rostrum. The extent of this contact remains constant throughout subsequent development, and in physically mature animals the two bones fuse along part or all of the zone of contact.

As in the spotted porpoise, distal fusion of the maxillaries and premaxillaries progresses variably, but begins roughly at puberty. In a subsample of 15 specimens, for which degree of sexual maturity was determined by histological examination of the gonads, in all the mature animals (5 males and 6 females with > 5 to > 10 dentinal layers) the maxillaries and premaxillaries have fused, whereas they have not fused in any of the

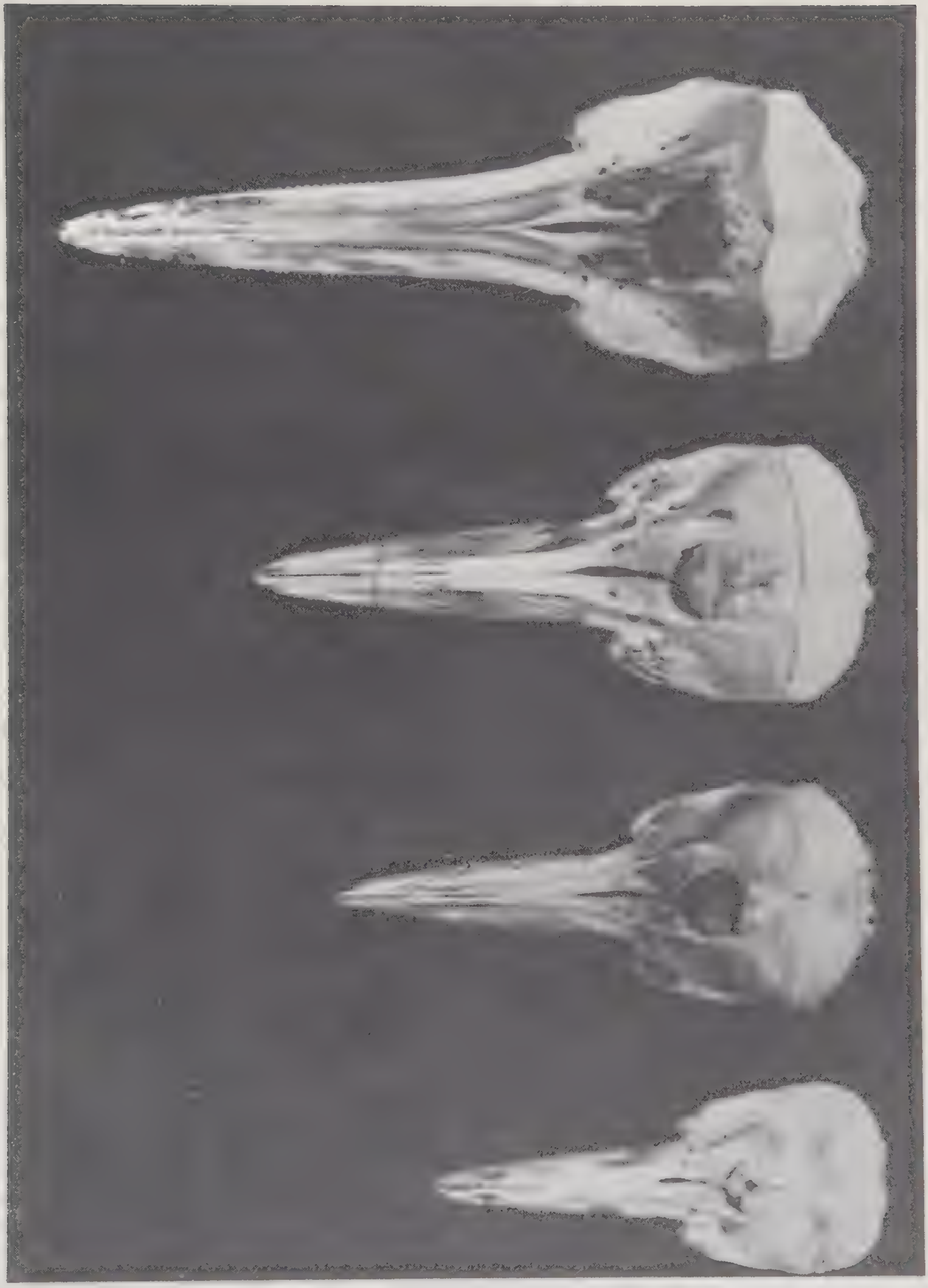

Figure 62. Dorsal views of crania of developmental series of spinner porpoise: (bottom to top) LACM no. 27430, calf of unknown sex, no postnatal dentinal layers, Class I; USNM no. 395601, immature female, one layer, Class II; USNM no. 395531, immature male, two layers, Class III. USNM no. 395396, physically mature female with occluded teeth, Class IV.

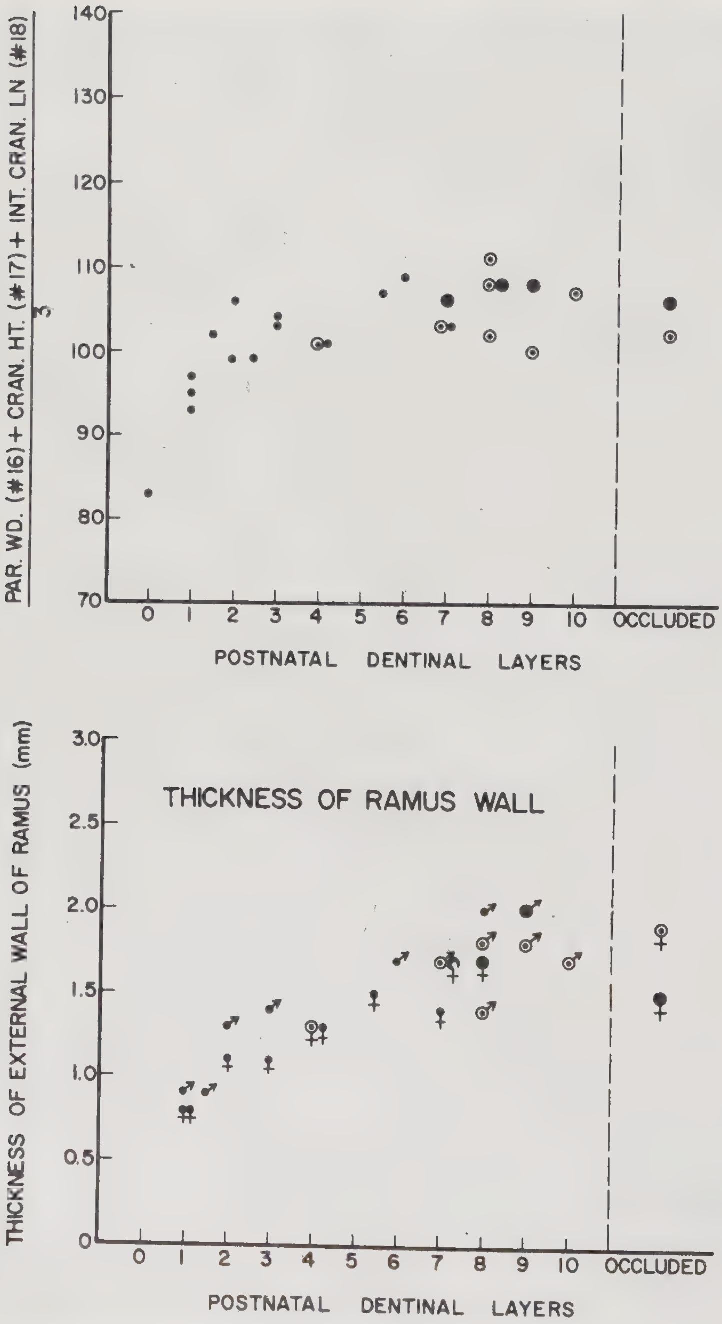

Figure 63. Development of skull of spinner porpoise: scatterplots of (top) average dimension of braincase and (bottom) thickness of ramus wall on number of postnatal dentinal layers. Small symbols are physically immature specimens. Large solid symbols are mature. Circled symbols are specimens of unknown degree of maturity.

4 large subadults (2 males and 2 females, with 2-4 dentinal layers). In some specimens in which fusion has occured, including some very old ones, a trace of the former juncture of the bones remains in the form of a groove extending to the end of the rostrum; in other specimens all traces of the juncture are obliterated in the distal 4 or 5 centimeters of the rostrum. The obliteration does not appear to be at all correlated with age.

Although with age the maxillaries and premaxillaries thicken slightly at the tip of the rostrum, such thickening is not nearly as extensive as in the spotted porpoise, in which physically mature specimens have noticeably heavier and blunter snouts than younger, though sexually mature, specimens. Some subadults have appreciably more attenuate snout tips, but most development of the rostrum and mandible tips appears to be accomplished before puberty.

Thickness of the external wall of the ramus, measured at the last tooth and at mid-height, increases with age (fig. 63), and mandibles of physically mature specimens are usually perceptibly heavier than those of younger specimens. One of the stoutest mandibles encountered in the series examined, however, was that of a physically immature male with only 8 layers in the dentine, indicating that the correlation is not a very close one.

The alveoli, especially in the maxillaries, do not develop at the same rate along the entire length of the tooth row; as a result the more distal teeth remain very insecurely anchored in quite large specimens. Distal development of discrete alveoli appears to coincide approximately with the onset of distal fusion of the maxillaries and premaxillaries and the attainment of sexual maturity, as opposed to the situation in the spotted porpoise, in which development of the alveoli progresses at an even rate along the length of the tooth row and alveoli are discrete in large sexually immature subadults. Distal development of the alveoli in some spinners is even more protracted, however; one specimen with 5 1/2 postnatal dentinal layers exhibits distal fusion but has only a furrow distally for anchorage of the teeth.

The rostrum develops more precociously in the spinner than in the spotted porpoise (compare fig. 64 with fig. 17): adult lengths are attained in subadults with only 2-3 layers. The same is true for the other measurements related to length of the rostrum. These include the measurements to the external and internal nares (nos. 8 and 9), tooth row lengths (nos. 32 and 37), and the length of the ramus (no. 38).

The shape of the rostrum (rostrum length/rostrum width in fig. 64) changes more in early development of the spinner than it does in the spotted porpoise. This is because of the early lengthening of the rostrum and not because of a difference in the rate of development of width. This growth spurt is also reflected in the early instability of other ratios based on rostrum length (fig. 64).

Fusion of the hyals is much more rapid, and there is less variation in degree of fusion in the spinner than in the spotted porpoise (compare fig. 65 top with fig. 20).

Hearing and vision apparatuses. The hearing apparatus develops as in the spotted porpoise; adult configuration is achieved in individuals with 2 postnatal dentinal layers. The orbit also develops similarly; adult size is reached in animals with 2-4 layers.

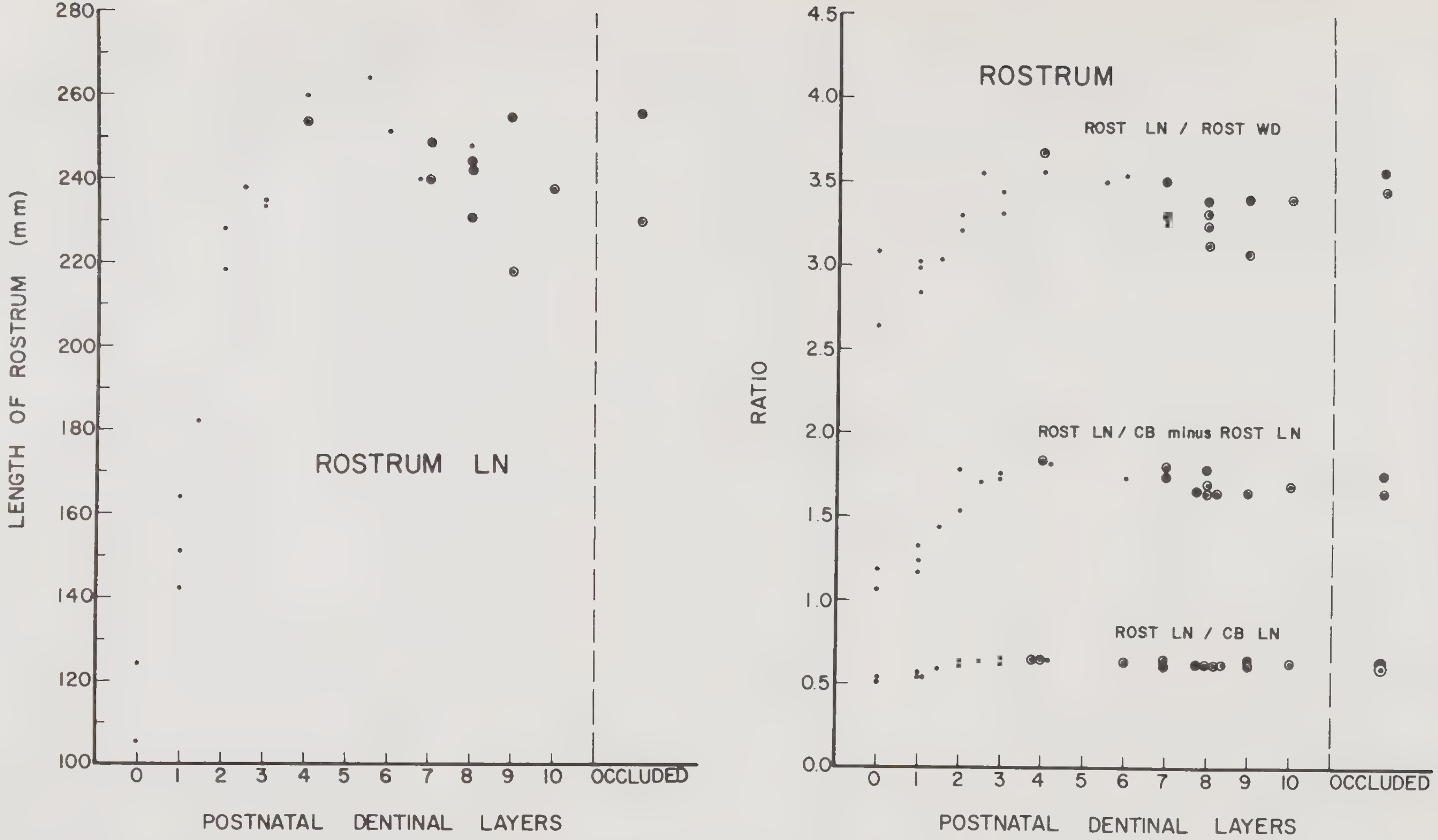

Figure 64. Development of skull of spinner porpoise: scatterplots of (left) rostrum length and (right) proportional rostrum lengths on number of dentinal layers. Larger solid dots are physically mature; circled dots are specimens of unknown degree of physical maturity.

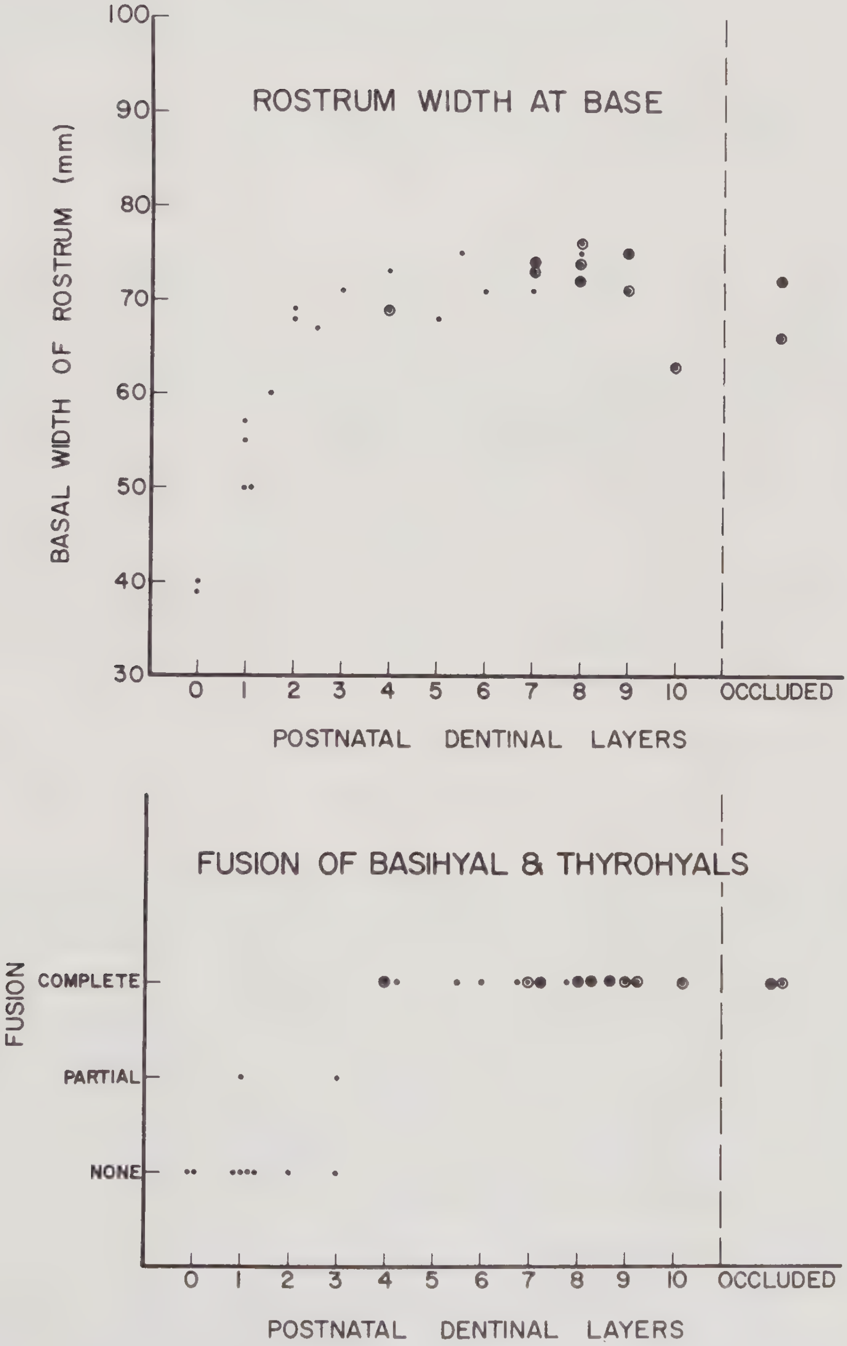

Figure 65. Development of skull of spinner porpoise: scatterplots (top) rostrum width and (bottom) degree of fusion of hyals on number of dentinal layers. Symbols same as figure 64.

Breathing and sound-producing apparatus. Facial telescoping proceeds faster in the spinner than in the spotted porpoise; adult configuration is attained in immature specimens with only 2 dentinal layers (fig. 66a), although widths of facial elements develop as in the spotted porpoise.

In specimens with more than 4 dentinal layers, the nasals are firmly fused to the frontals in all except one (with 6 layers). The outlines of the nasals are obliterated to varying extent with age.

Summary. Some functional elements of the skull of the spinner propoise, including the braincase, feeding apparatus, and breathing and sound-producing apparatus, grow more rapidly than they do in the spotted porpoise. Two alternative explanations exist: growth patterns are the same in the two forms and tooth layers are laid down at different rates, or tooth layers are laid down at the same rate in both forms but development in these features is faster in the spinner. The latter seems more likely, because the hearing apparatus and some features of the other systems, including the alveoli and parieto-occipital telescoping, develop at a similar or slower rate than in the spotted porpoise. In addition, no features in the spinner show the protracted growth into adulthood and physical maturity that exist in the spotted porpoise. I conclude, therefore, that developmental patterns are different in the two forms. The spinner is more precocious in most features. All skull with 4 or more postnatal dentinal layers, or with fused premaxillaries and maxillaries, are included below in the samples for analyses of sexual dimorphism and of individual and geographical variation.

Postcranial skeleton

The postcranial axial skeleton is shown in figure 67.

Axial postcranial skeleton. The anterior face of the atlas does not develop as precociously as it does in the spotted porpoise (compare fig. 66b with fig. 27d), but more resembles that of other features of the atlas, such as length of the neural spine. The growth continues at least until attainment of physical maturity.

Length of the 23d centrum (fig. 66c) shows a different pattern of increase than for the spotted porpoise (fig. 27). Although the small sample size precludes firm conclusions, it appears that growth of the torso is not so protracted as in the spotted porpoise, an interpretation again consistent with the external morphometric data. The pattern of fusion of vertebral epiphyses indicates that the onset of physical maturity in this species is on the average attained earlier than in the spotted porpoise (fig. 27) (with 7-8 layers, as opposed to 8-10 layers), a phenomenon consonant with earlier attainment of maximum total length.

The ribs and sternum (fig. 68) develop as in the spotted porpoise, with respect to the shape and fusion of the elements, but absolute growth posteriorly, as for other posterior thoracic and lumbar elements of the skeleton, stops earlier in the spinner than in the spotted porpoise (compare fig. 66d with fig. 22). Adult size is attained when 4-5 dentinal layers have been laid down.

As in the spotted porpoise, no developmental trend was noted in size of the manubrial foramen, but the largest foramen in 18 specimens examined was only 3 mm long. An

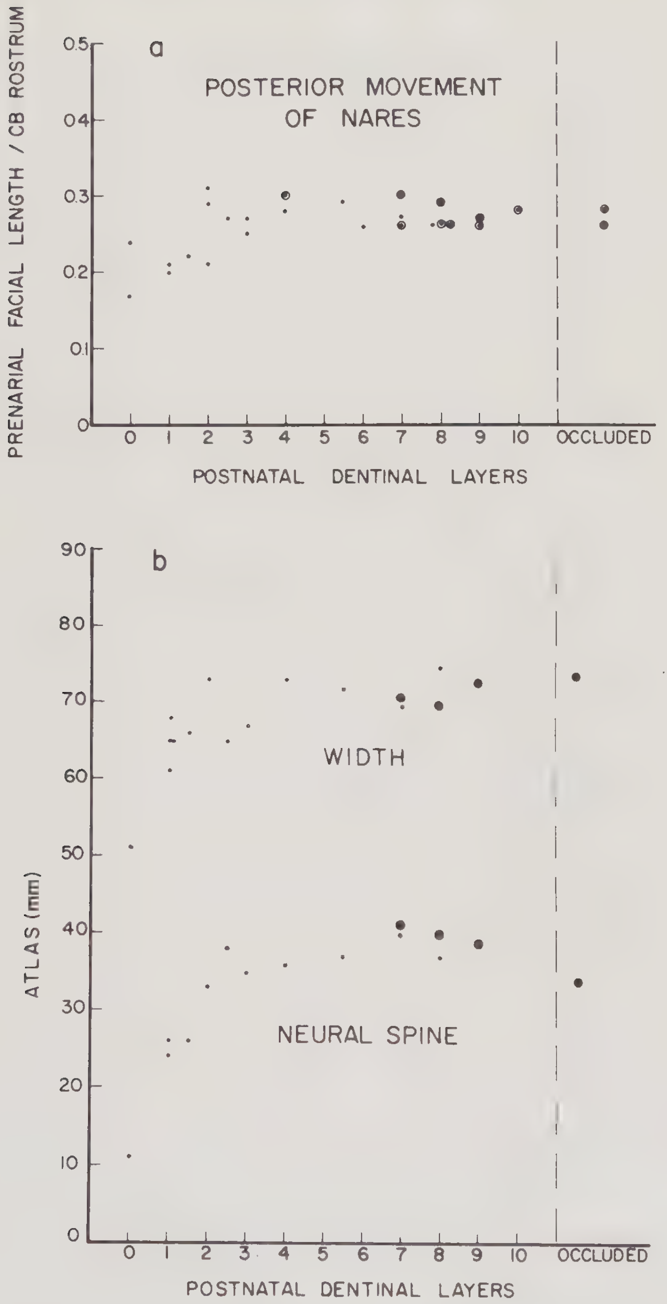

Figure 66. Development of skeleton of spinner porpoise: scatterplots of (a) prenarial facial length and (b) measurements of atlas (continued).

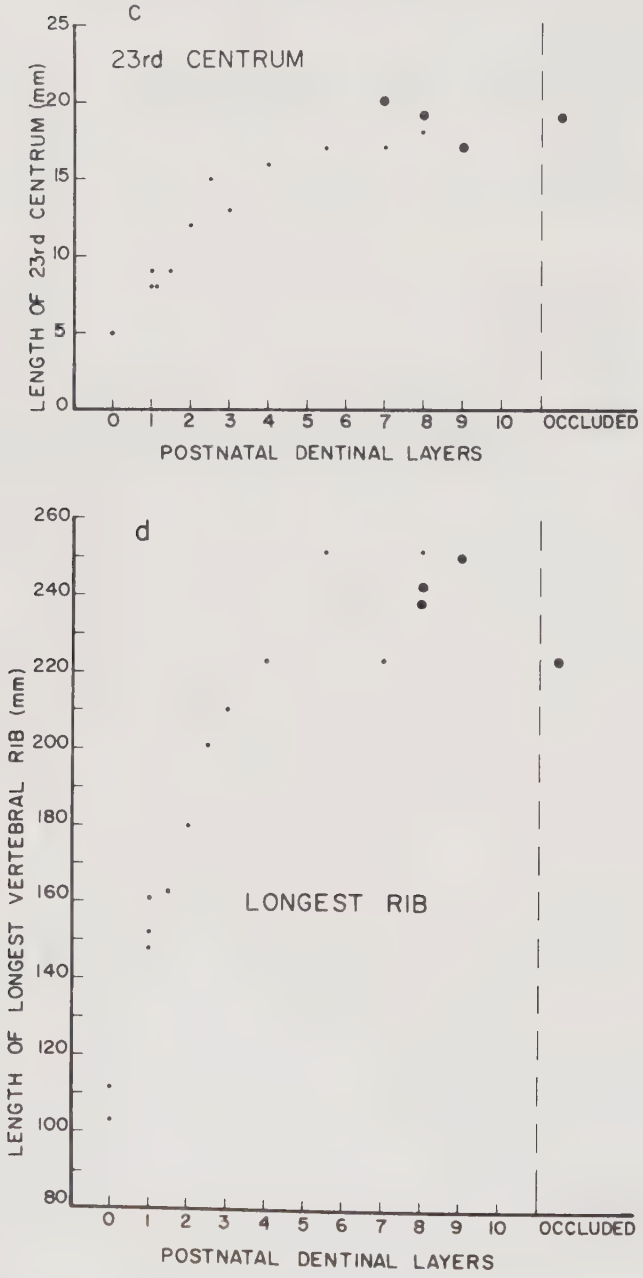

Figure 66 (continued). Development of skeleton of spinner porpoise: scatterplot of (c) length of 23rd centrum and (d) length of longest rib (continued).

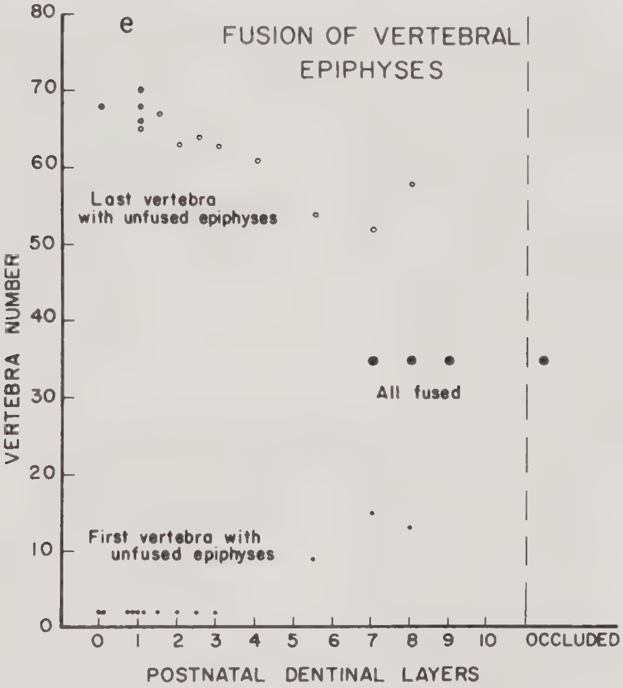

Figure 66 (continued). Development of skeleton of spinner porpoise: scatterplot (e) of progress of fusion of vertebral epiphyses on number of dentinal layers in spinner porpoise.

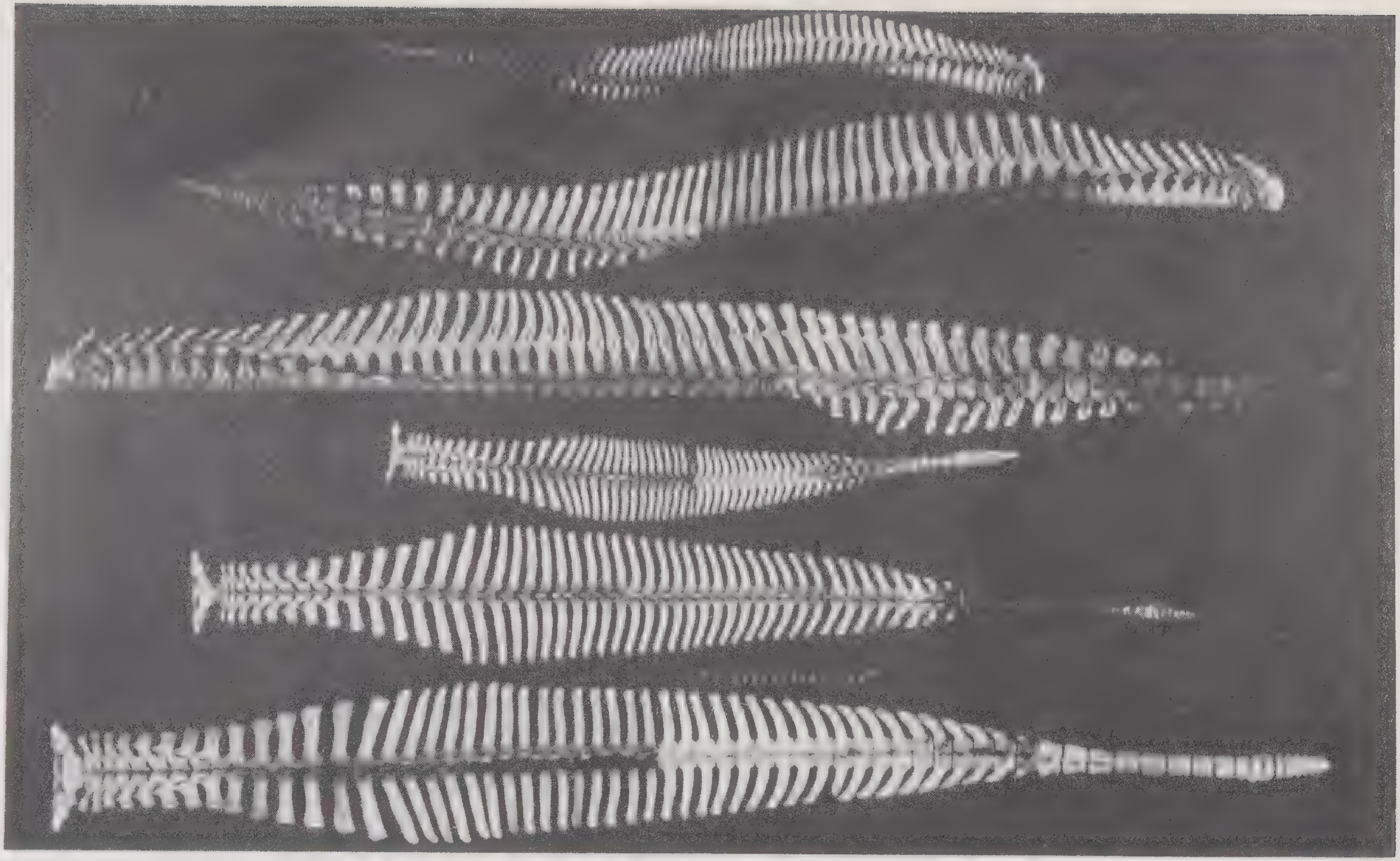

Figure 67. Development of postcranial axial skeleton of spinner porpoise: lateral and dorsal views of Class II (USNM no. 395601), Class III (USNM no. 395411), and Class IV (USNM no. 395396) specimens.

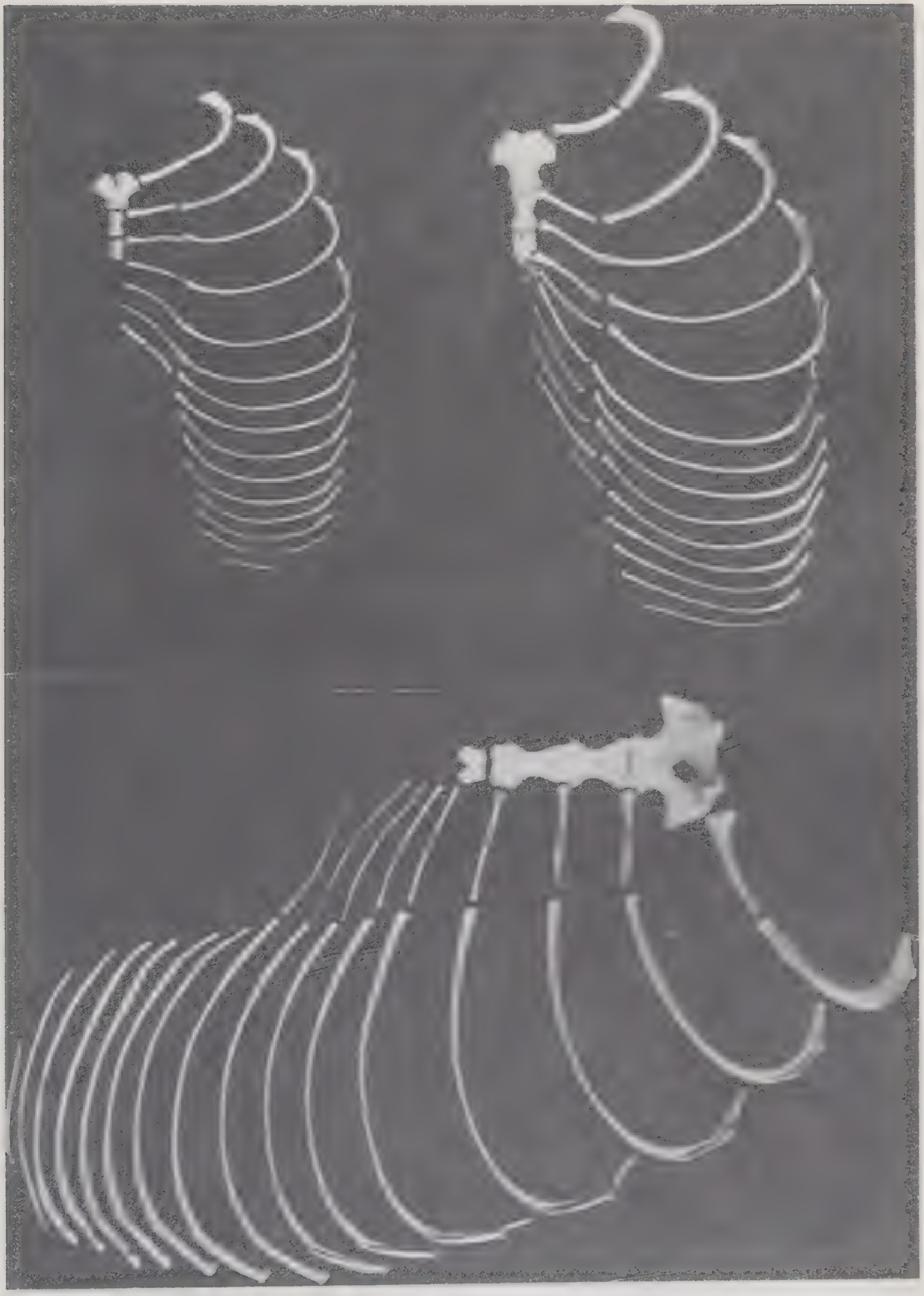

Figure 68. Ribs and sternae of specimens in figure 67.

adult specimen not in the developmental series had a foramen 10 mm long. It thus appears that ossification of the manubrium varies less than it does in the spotted porpoise.

Anterior appendicular skeleton. The scapula (fig. 69) and forelimb (fig. 70) develop as in the spotted porpoise, with some minor differences. In the specimens examined, the trapezium is ossified in neonatals, as opposed to its unossified condition in newborn specimens of the spotted porpoise. The element called the trapezoid by Fraser (1950) is not present in any specimen examined. The fifth metacarpal is also present in all young specimens examined, although absent in one manus of one adult.

None of the 18 specimens had ossified phalanges in the first digit. Hyperphalangy is more developed in the spinner than in the spotted porpoise in digits II and III (compare fig. 71 with fig. 33). There are 8 ossified phalanges at birth in digit II, with a maximum of 10 in older specimens. Digit III has 5 or 6 at birth, with a maximum of 7 in older animals. Digit IV is constant at 2-3 phalanges, and digit V has 0-2 ossified phalanges in adults as opposed to 0-1 in the spotted porpoise. Digits II, III, and V show change during development in number of ossified phalanges, with adult number attained in all three by the time 4 layers have been laid down in the teeth.

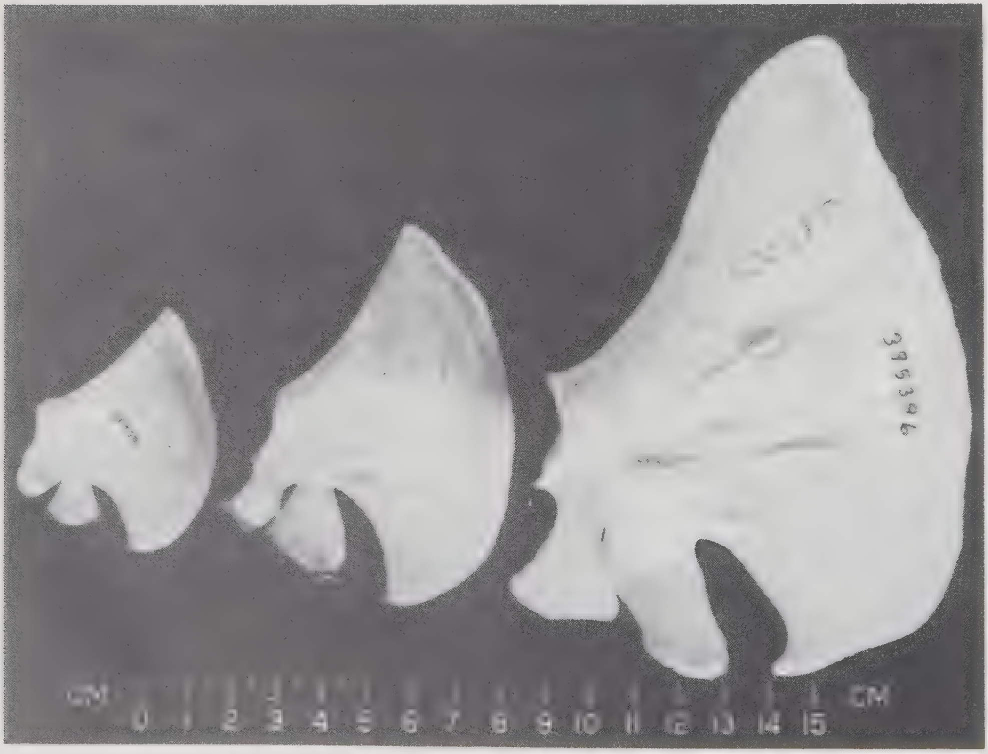

Figure 69. Scapulae of Class II (far left, LACM27430) specimen and same Class III and IV as specimens in figure 67.

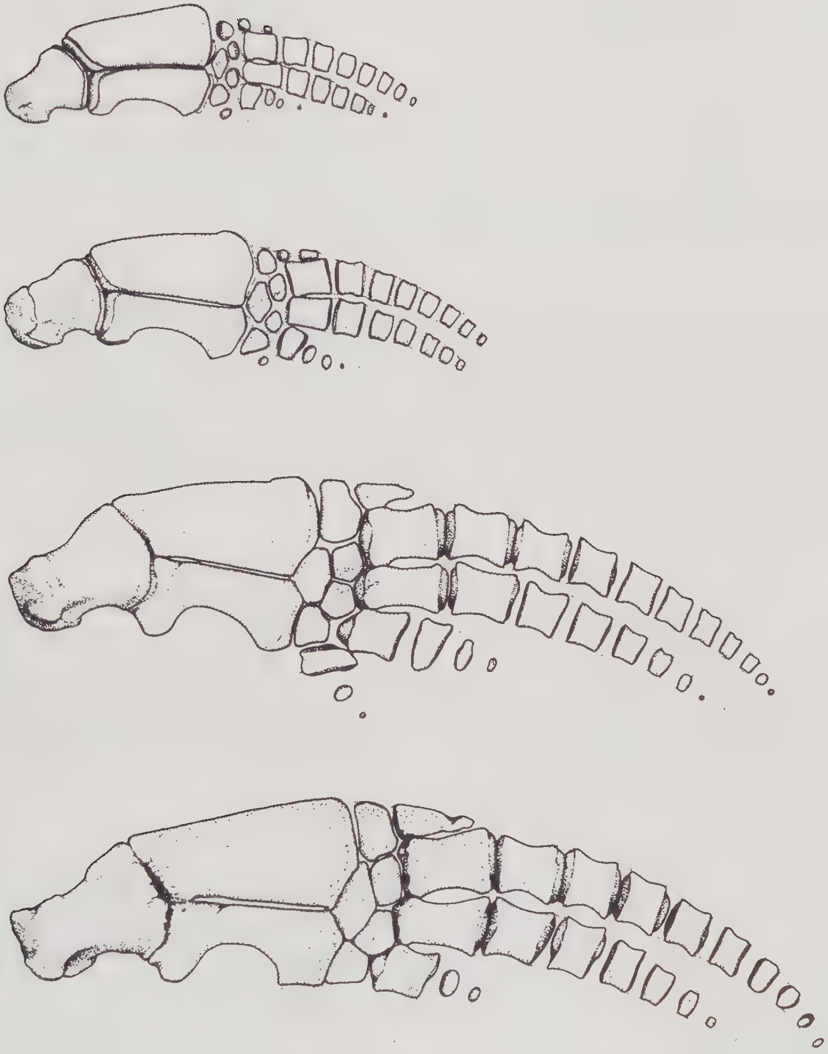

Figure 70. Development of forelimb skeleton of spinner porpoise: (top to bottom) Class I, II, III and IV specimens.

The epiphyses fuse to the humerus (fig. 71) earlier in the spinner than in the spotted porpoise (when 3-4, as opposed to 5-8 dentine layers have been formed), again prior to the fusion of the vertebral epiphyses.

Posterior appendicular skeleton. The available sample of pelvic rudiments is small (fig. 72), but it is obvious that while the trend is to increase in size with development, there is great variation in the course of development. For example, the smallest adult female pelvics are found in the oldest specimen. It appears that the adult female pelvics are in general less elaborate than in the spotted porpoise.

Summary. The postcranial skeleton of the spinner develops less precociously than the most anterior parts and the development is less protracted in its thoracic and lumbar regions than in the spotted porpoise, rendering overall growth more isogonic. It seems that adult configuration of the axial skeleton is attained earlier in the spinner than in the spotted porpoise, approximately coincidental with the attainment of sexual maturity. The small sample size of complete adult skeletons precludes a firm conclusion.

Sexual Dimorphism

Dimorphism at $\alpha = 0.05$ was found only in the braincase, feeding apparatus, and postcranial skeleton (table 17). The values of t, however, are all quite low, and it is likely that all or most of the "differences" result from chance alone, that is, from the large number of simultaneous tests. I therefore conclude that sexual dimorphism is negligible in the eastern Pacific spinner, except for the pelvics, and in any case is inadequate for determining the sex of specimens.

Individual Variation

The single-school series of osteological specimens available to me were not large enough to allow as detailed an examination of individual variation as was accomplished for the spotted porpoise. Three small series from the tuna fishery of 6, 7, and 5 specimens containing 4, 4, and 5 "adult" skulls, respectively, were available and the ranges for cranial measurements and, in one of the series, for both cranial and postcranial meristics, are presented (table 18).

Each of these short series shows a striking range of variation (figs. 73, and 76 and 77 below). These pairs are referred to below as "A" (figs. 76 and 77), "B" (fig. 73), and "C" (fig. 73).

In A, the differences are primarily in length; both the braincase and the rostrum are shorter in the smaller skull. Parietal width, however, is identical in the two specimens. In B, the smaller skull is both shorter and narrower than the larger. Most of the nonproportional difference in width of the postrostral portion of the skull is in development of the facial area. The narrow supraorbital shelf and premaxillary shield in the smaller specimen are notable (fig. 76). The smaller skull is from a large sexually mature male. The premaxillaries and maxillaries are fused dorsally the full length of the rostrum, but in size and proportions the skull is subadult (compare with Class III skull in fig. 62). This infantilism

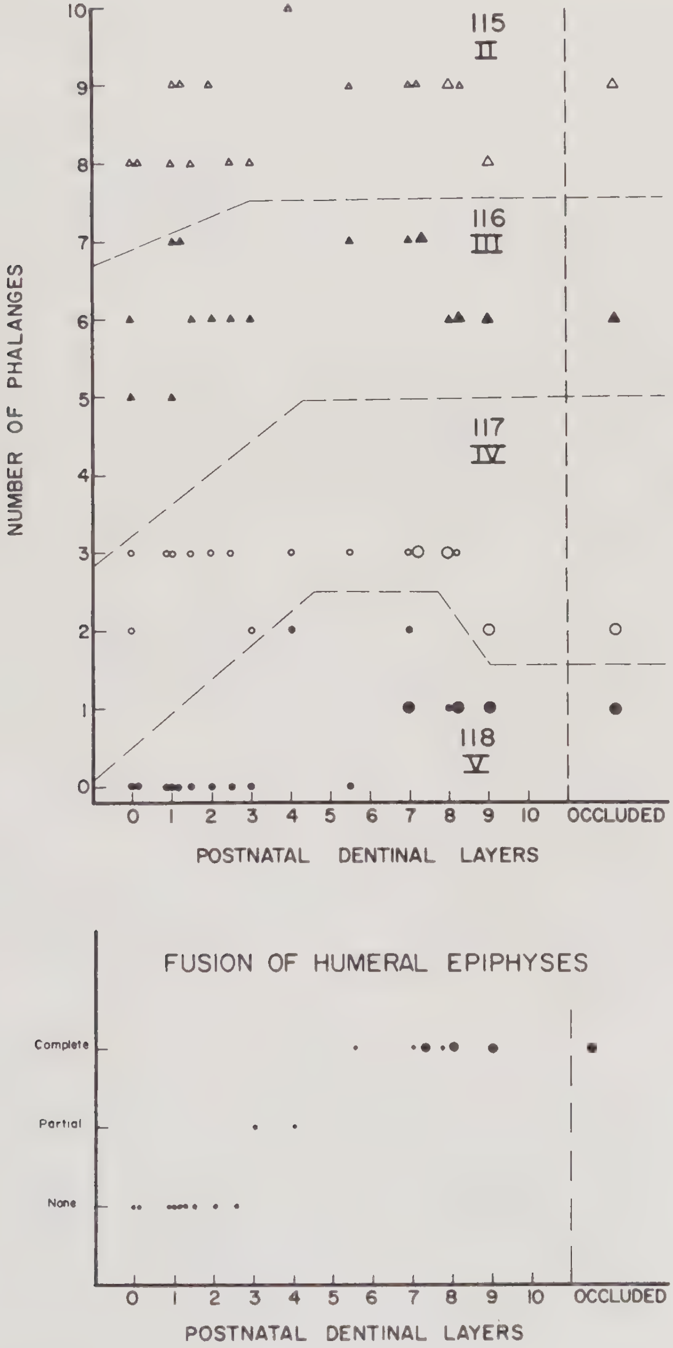

Figure 71. Development of forelimb of spinner porpoise: scatterplots of (top) number of ossified phalanges and (bottom) degree of fusion of humeral epiphyses on number of dentinal layers. Large symbols are physically mature specimens.

Table 18. Cranial measurements and meristics for three single-school series of spinner porpoise

Variable	Unit	A		B		C	
		Number of specimens	Range	Number of specimens	Range	Number of specimens	Range
1. Condylobasal length	mm	4	351-379	5	369-396	4	365-419
2. Rostrum length	mm	4	218-240	5	230-254	4	227-271
3. Rostrum width at base	mm	4	71-74	5	66-76	3	73-78
4. Rostrum width at 60 mm	mm	4	46-50	5	47-53	3	52-57
5. Rostrum width at midlength	mm	4	39-43	5	40-44	3	44-46
6. Premaxillary width at rostral midlength	mm	4	16-20	5	17-21	3	21-24
7. Rostrum width at 3/4 length	mm	4	29-34	5	27-33	3	34-36
8. Rostrum tip to external nares	mm	4	252-282	5	269-296	4	265-308
9. Rostrum tip to internal nares	mm	4	257-280	5	275-294	4	264-307
10. Preorbital width	mm	4	128-136	5	127-136	4	138-145
11. Postorbital width	mm	4	140-151	5	141-154	4	152-158
12. Least supraorbital width	mm	4	125-136	5	125-136	4	138-141
13. External nares width	mm	4	35-43	5	37-41	4	37-42
14. Zygomatic width	mm	4	139-147	5	139-152	4	152-158
15. Greatest width of premaxillaries	mm	4	49-63	5	58-62	4	60-66
16. Parietal width	mm	4	121-124	5	121-132	4	130-138
17. Braincase height	mm	4	85-88	5	83-92	4	87-92
18. Braincase length	mm	4	95-99	5	98-108	4	94-108
19. Posttemporal fossa length	mm	4	41-51	5	42-57	4	46-56
20. Posttemporal fossa width	mm	4	32-36	5	30-38	4	40-44
21. Temporal fossa major diameter	mm	4	29-30	5	30-32	4	30-34
22. Temporal fossa minor diameter	mm	4	15-23	5	19-23	4	16-23
23. Projection of premaxillaries	mm	3	14-20	5	15-25	—	—
24. Nasals to crest	mm	4	22-36	5	25-44	4	26-31

25.	Orbit length	mm	4	38-40	5	38-41	4	41-42
26.	Antorbital process length	mm	4	39-40	5	39-43	4	38-41
27.	Internal nares width	mm	4	39-41	5	39-42	4	41-48
28.	Pterygzoid length	mm	4	45-59	5	54-61	4	54-60
29.	Occipital overhang	mm	4	0-6	5	2-11	4	0-11
30.	Bulla length	mm	4	25-28	4	27-29	4	26-30
31.	Periotic length	mm	4	24-26	5	24-25	4	26-27
32.	Upper tooth row length	mm	4	192-214	5	201-219	2	192-235
TEETH								
33.	Upper left	no.	6	51-57	4	49-52	4	51-55
34.	Upper right	no.	6	51-56	4	47-54	5	51-55
35.	Lower left	no.	6	49-53	5	45-50	5	50-53
36.	Lower right	no.	7	48-53	5	45-52	6	48-54
37.	Lower tooth row length	mm	4	188-219	5	191-218	3	190-234
38.	Ramus length	mm	4	301-321	5	309-336	4	308-360
39.	Ramus height	mm	4	47-53	5	50-55	4	50-60
40.	Mandibular fossa length	mm	4	80-89	5	83-91	4	84-95
41.	Deviation from symmetry	degrees	4	8-11	5	7-9	4	7-13
42.	Basihyal length	mm	4	26-32	5	25-31	4	27-31
43.	Basihyal width	mm	4	30-36	4	32-38	4	34-35
44.	Thyrohyal width	mm	4	13-19	4	15-18	4	16-23
45.	Thyrohyal length	mm	4	41-48	4	36-58	4	43-49
46.	Stylohyal width	mm	4	13-16	4	12-16	4	12-17
47.	Stylohyal length	mm	4	59-67	4	56-68	4	65-67

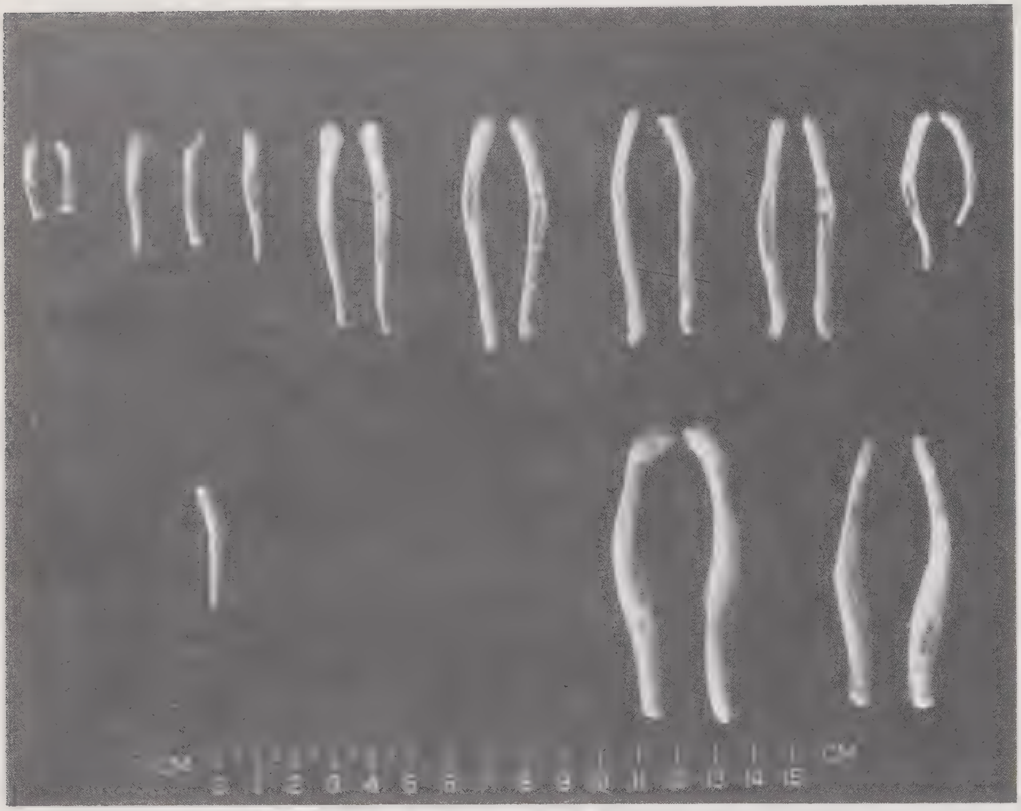

Figure 72. Development and variation of pelvic rudiments in spinner porpoise. Rightmost pair on top (females) and bottom (males) are from physically mature specimens.

is even more pronounced in the hearing system (fig. 74). The small skull is the only one of all those examined on which the occipital crest has a posteriorly directed overhang (approximately 1 mm). In C, as in A, the main difference between the two skulls is in length; the skulls are of nearly identical width. The larger skull is proportionately longer in the postnarial frontal region. In all three pairs of skulls, the size, shape, and orientation of the posttemporal fossae are notably disparate.

Geographical Variation

Pronounced geographical variation exists in the skeleton of the spinner porpoise. The available skeletal material from known localities in the eastern Pacific and Hawaii comprises 85 specimens. The area covered in the eastern Pacific extends from Tres Marias Islands in the north to Costa Rica and offshore to about 135°W longitude (fig. 75).

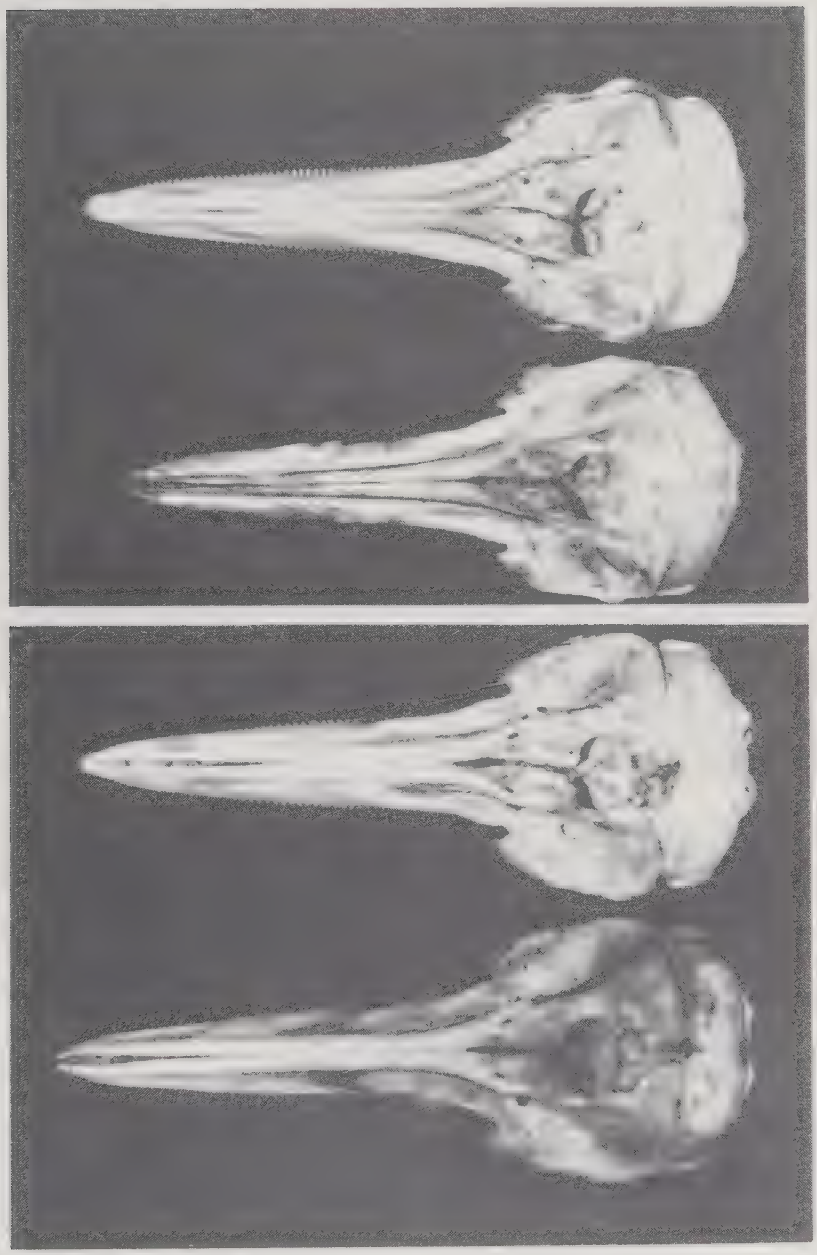

Figure 73. Individual variation of skull of spinner porpoise within school; dorsal view of cranium of spinner porpoise from each of two single-school series: pair B (bottom) SWFC no. CV 240 (pterygoids damaged), male, 8 layers, Class IV, and USNM no. 395275, male, 10 layers, Class IV; pair C (top) USNM no. 395271, male, 9 layers, Class IV, and USNM no. 395273, male, 7 layers, Class IV. See figures 76 and 77 for an additional pair of specimens (pair A: USNM no. 395031 and USNM no. 396170) from a single-school series (continued).

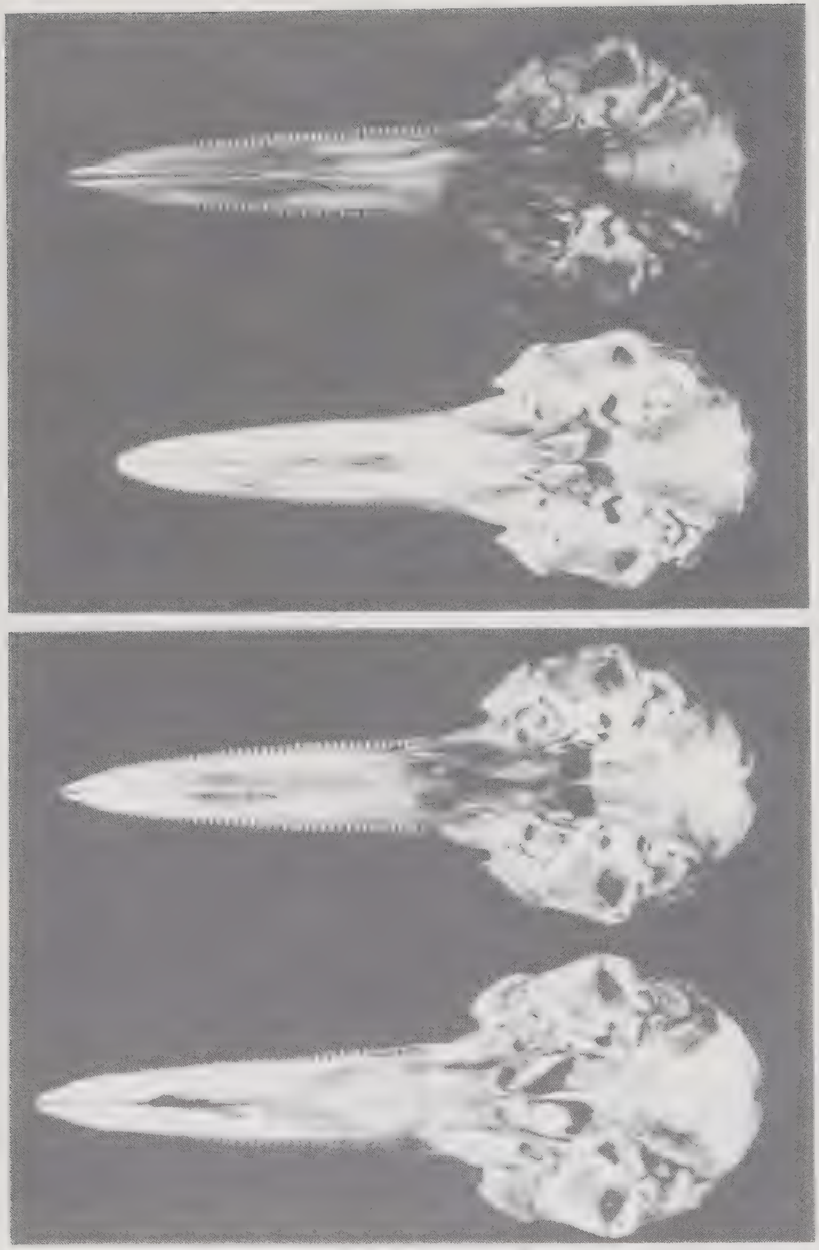

Figure 73 (continued). Individual variation of skull of spinner porpoise within school: ventral view of skulls on previous page.

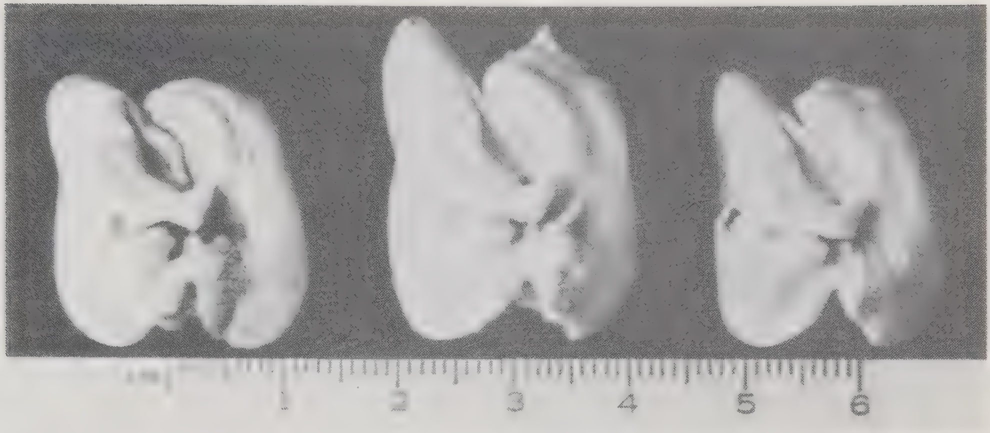

Figure 74. Tympanoperiotic bones of adult spinner porpoise USNM no. 395271 (on right) compared with those of normal adult (center) and calf (left) to illustrate infantilism.

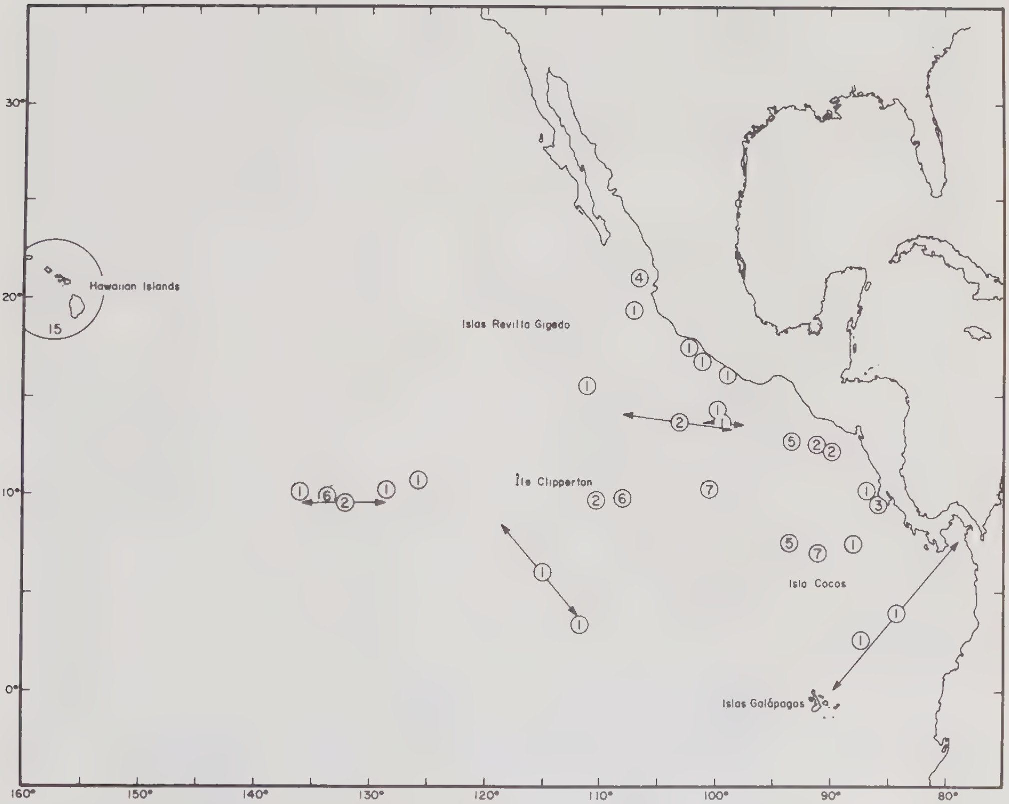
30°
20°
10°
0°
Hawaiian Islands
15
Islas Revilla Gigedo
Île Clipperton
Isla Cocos
Islas Galápagos
160°
150°
140°
130°
120°
110°
100°
90°
80°

Figure 75. Provenance of specimens used in analysis of geographical variation in skeleton of spinner porpoise.

Skeletal specimens included in analysis of geographical variation

Costa Rican--3 from 9°47′N, 85°42′W (USNM 395931-3), 1 from 9°58′N, 86°03′W (USNM 395934).

Eastern–4 from 12°51′N, 93°18′W (USNM 395396, 395531, 395533-4), 7 from 7°11′N, 90°32′W (USNM 395260, 395270-3, 395526, 395593), 5 from 7°20′N, 92° 30′W (USNM 395274-5, SWFC - CV 240-1, SWFC - CV 245), 2 from ~21°16′N, 106° 16′W (LACM - WAW 50, 55), 1 from ~18°N, 102°12′W (LACM - WAW 54), 1 from 14° 30′N, 99°35′W (LACM - WAW 60), 1 from ~14°20′N, 107°20′W (LACM - RLB 405), 2 from 12°32′N, 91°04′W (USNM 324974-5), 1 from 16°15′N, 98°55′W (USNM 395930), 1 from 12°30′N, 92°53′W (SDMNH 21427), 1 from 13°30′-14°06′N, 98°-100°56′W (CAS 15665), 1 from 13°33′-14°02′N, 99°47′-102°02′W (CAS 15666), 1 from 13°33′-14°02′N, 99°-108°W (MVZ 140641), 7 from 9°50′-10°36′N, 99°47′-102°02′W (CAS 15667-9, MVZ 140642 and 140645, UCMP 86287, SWFC - LGB - WFP 28), 1 from ~3°N, 87°W (USNM 395026), 1 from 7°21′N, 87°14′W (USNM 396169), 1 from Pacific Ocean between Panama and Galápagos Islands (USNM 23302), 1 from ~21°35′N, 106°40′W (USNM 88976), 1 from ~17°N, 100°45′W (LACM - WAW 58), 1 from ~18°20′N, 106°40′W (SDMNH 21200), 2 from ~12°20′N, 80°50′W (CAS 13821, 13828), 1 from ~21°43′N, 10°47′W (MMBL 1967-102).

Whitebelly–2 from 7°40 - 8°N, 107°W (USNM 395409, 395411), 4 from 7°56′-8°N, 106°36′-50′W (USNM 395412-4, 395600), 2 from 8°N, 109°45′W (USNM 395599, 395601), 2 from 9°28′-55′N, 128°20′-136°08′W (USNM 396023, 396030), 6 from 9° 47′N, 133°25′W (USNM 396017, 396021, 396031-2, 396036, 396170), 2 from ~11°N, 125°W (USNM 396035, 396168), 1 from 3°20′N, 110°44′W (USNM 396173), 1 from 3°20′N, 110°44′W or 8°19′N, 119°15′W (USNM 396174), 1 from 10°19′N, 135°38′W (USNM 396020).

Hawaiian–5 from Hawaiian waters (LACM 27095, LACM - RLB 240 and 242, TKO 050 and 295), 5 from Oahu (SWFC - WPSR0l, LACM - "Maka",LACM 27093, MMBL 1194, CAS 10529), 2 from Molokai (LACM - "Momona"- SLP - 02-66, LACM - "Opihi"). USNM = U.S. National Museum, Washington, D.C., SWFC = Southwest Fisheries Center, La Jolla, Calif., LACM = Los Angeles (Calif.) County Museum, SDMNH = San Diego (Calif.) Museum of Natural History, CAS = California Academy of Science, San Francisco, Calif., MVZ = Museum of Vertebrate Zoology, University of Calif., Berkeley, UCMP = University of California Museum of Paleontology, Berkeley, MMBL = Marine Mammal Biological Laboratory, Sand Point NAS, Seattle, Wash., MCZ = Museum of Comparative Zoology, Harvard University, Cambridge, Mass., TKO = University of Tokyo.

Cranial skeleton

Geographical variation in the skull of the spinner porpoise is shown in figures 76-80. Measurements and meristics are shown in table 19.

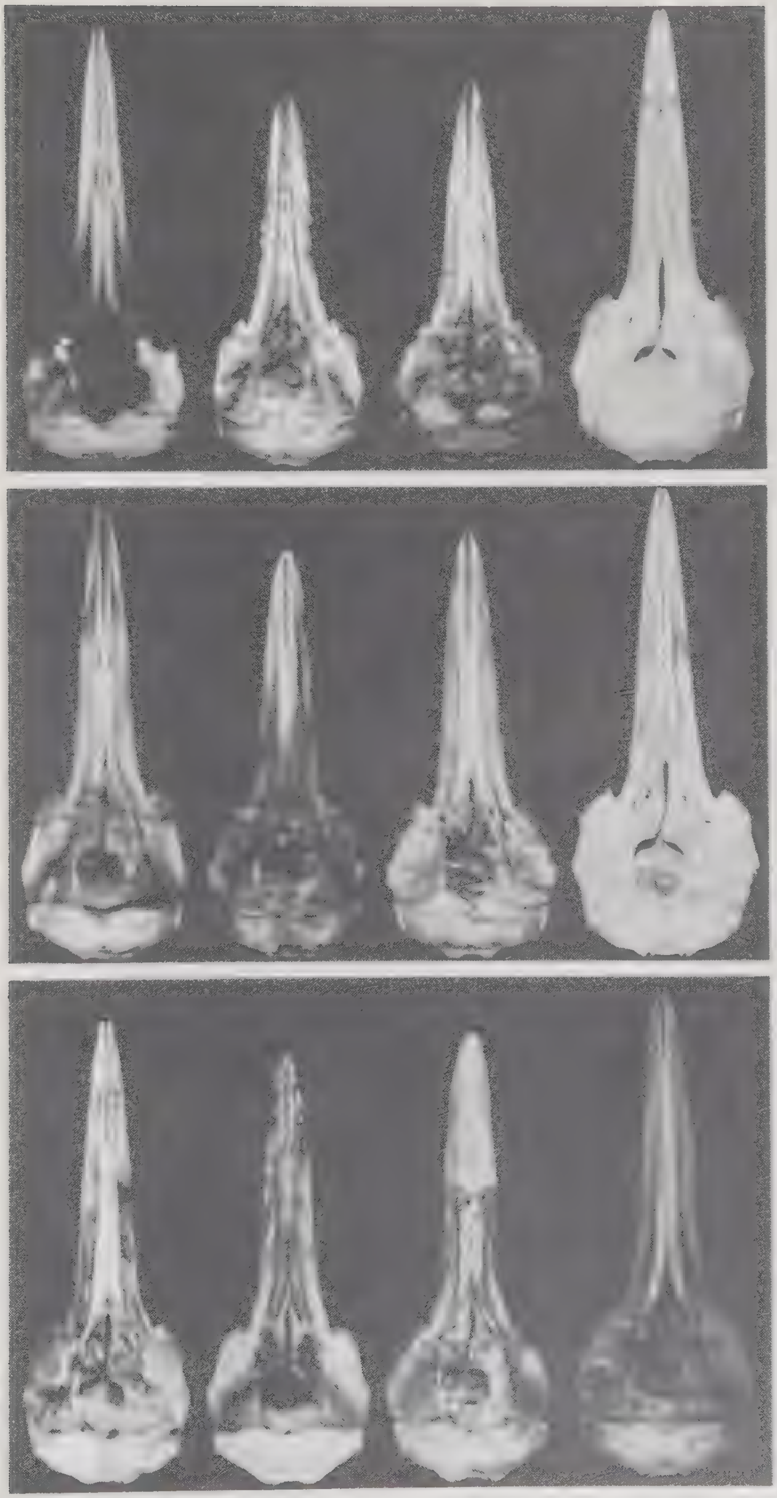

Figure 76. Geographical variation in skull of spinner porpoise: dorsal view of crania of (left to right) longest, modal and shortest intact skulls of (top to bottom) Costa Rican, eastern, whitebelly, and Hawaiian series. Costa Rican specimens are USNM nos. 395934, 395932, and 395931. Eastern specimens are USNM nos. 395271, 396026, and 395396. Whitebelly specimens are USNM nos. 395031, 395414, and 396170. Hawaiian specimens are TKO no. 050, LACM no. RLB 242, and TKO no. 295.

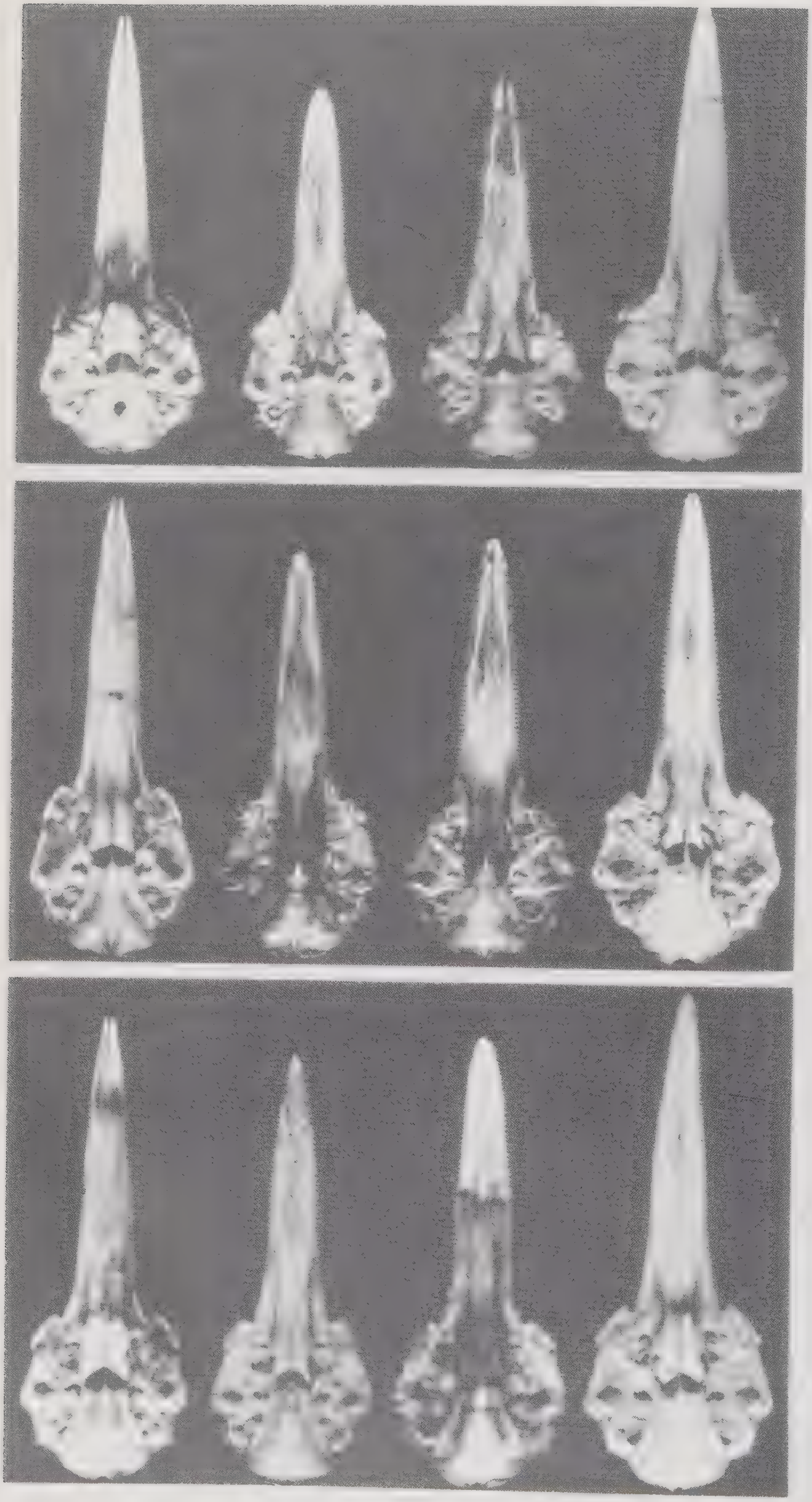

Figure 77. Ventral view of skulls in figure 76, in same order.

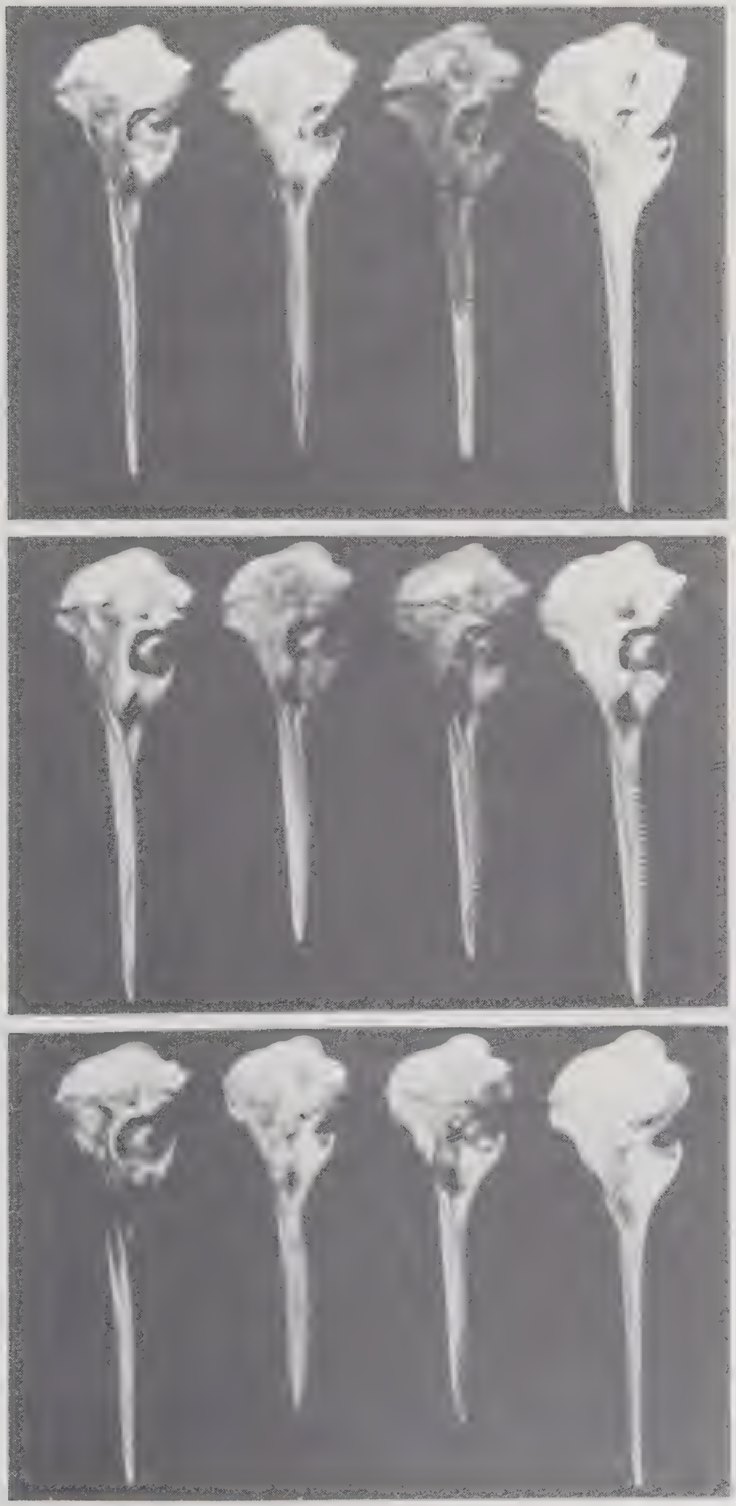

Figure 78. Lateral view of skulls in figure 76 (Costa Rican series at top, Hawaiian series at bottom); shortest skulls at top.

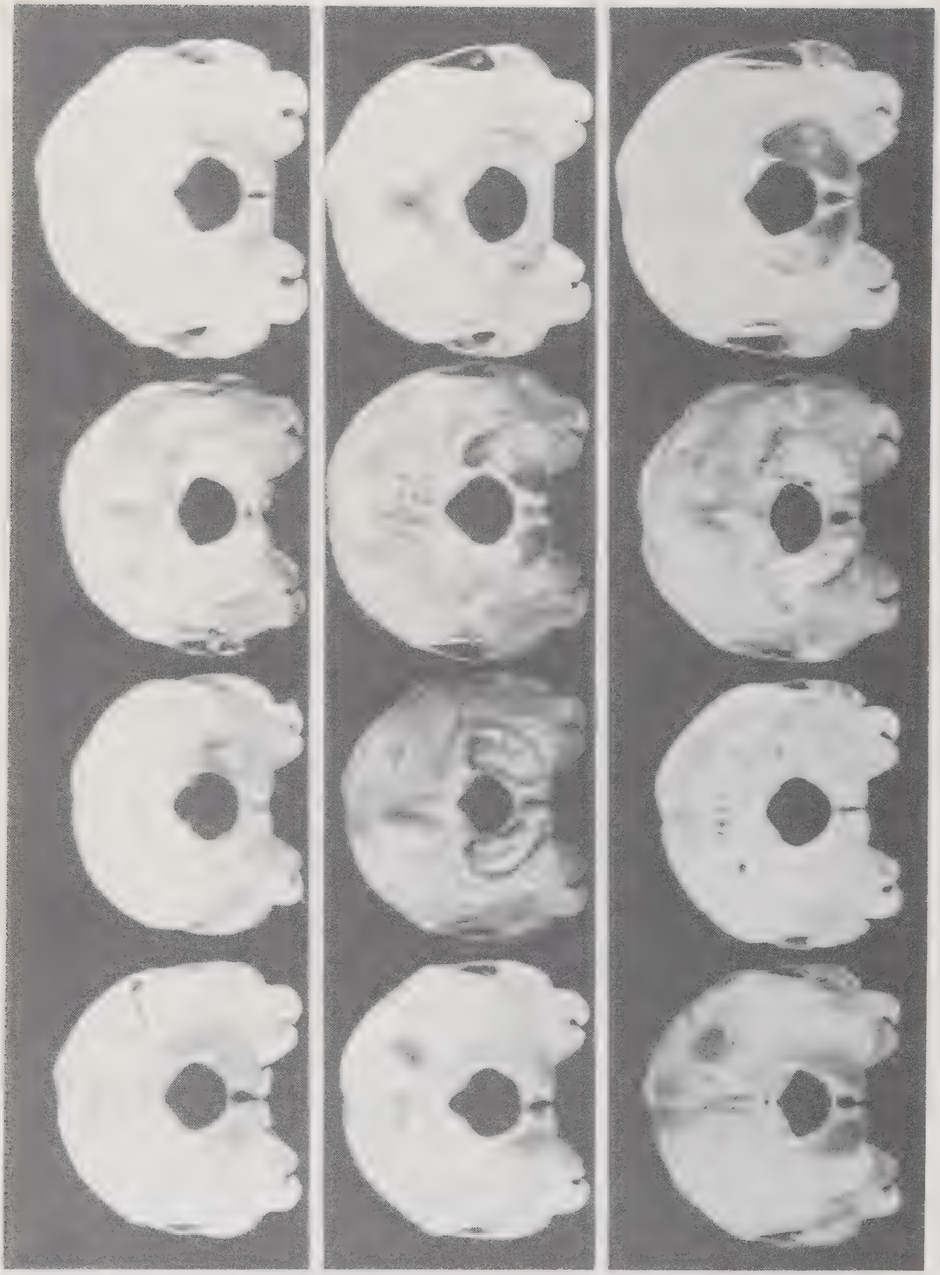

Figure 79. Occipital view of skulls in figure 76 (Costa Rican skulls at left; shortest skulls at top).

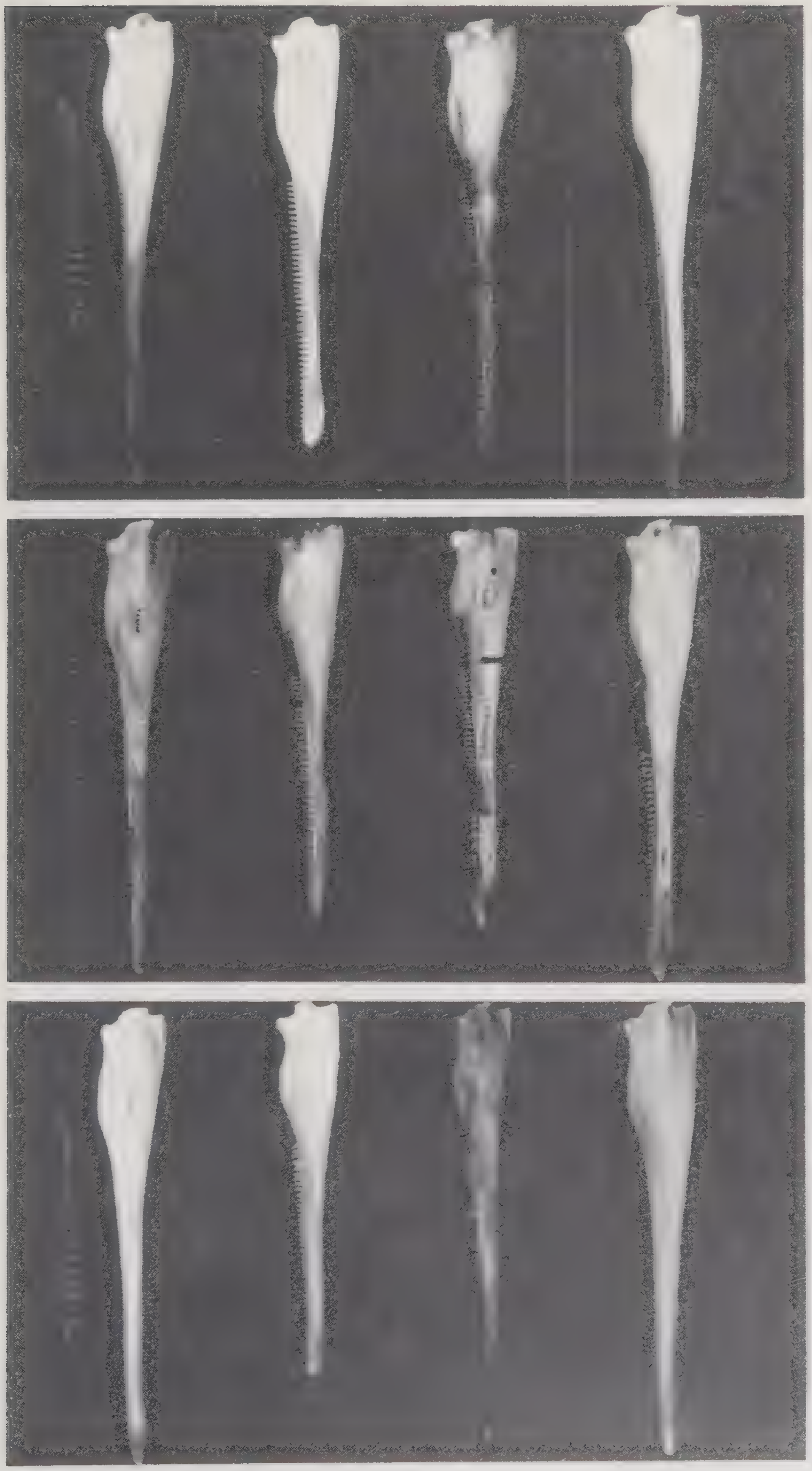

Figure 80. Lateral view of mandibles of skulls in figure 76, in same order as in lateral view (fig. 78). Note that mandible 395934 is erroneously labeled "395534."

Table 19. Skeleton measurements and meristics of Costa Rican, eastern, whitebelly, and Hawaiian spinner porpoise, with statistical comparisons (continued)

Variable	Unit	A. Costa Rican				B. Eastern				C. Whitebelly				D. Hawaiian				Absolute value of significant t, at $\alpha = .05$		
		Number of specimens	Range	Mean	Standard deviation	Number of specimens	Range	Mean	Standard deviation	Number of specimens	Range	Mean	Standard deviation	Number of specimens	Range	Mean	Standard deviation	A/B	B/C	C/D
1. Condylobasal length	mm	4	416-437	426.0	11.05	26	351-407	386.5	13.51	13	365-419	396.0	13.35	10	431-464	441.7	10.76	5.54	2.08	8.83
2. Rostrum length	mm	4	269-288	276.8	8.18	26	218-262	245.5	10.83	13	227-271	251.5	11.89	10	277-304	288.2	8.94	5.51	—	8.14
3. Rostrum width at base	mm	4	70-77	72.8	3.10	29	66-77	72.1	2.61	14	69-78	73.7	2.43	10	76-84	80.4	2.41	—	—	6.68
4. Rostrum width at 60 mm	mm	4	49-53	51.3	1.71	29	46-54	49.8	2.34	14	48-57	51.6	2.59	10	52-60	56.7	2.40	—	2.28	4.90
5. Rostrum width at midlength	mm	4	39-43	41.8	1.89	26	37-47	41.6	2.45	11	39-46	42.8	2.04	10	45-49	47.0	1.41	—	—	5.43
6. Premaxillary width at rostral midlength	mm	4	21-22	21.5	0.58	26	16-22	19.6	1.70	11	17-24	19.9	1.87	10	20-22	20.6	0.70	2.19	—	—
7. Rostrum width at 3/4 length	mm	4	28-30	29.3	0.96	26	26-36	30.5	2.56	11	29-36	31.8	2.52	9	31-34	32.6	1.01	—	—	—
8. Rostrum tip to external nares	mm	4	317-335	328.5	8.27	26	252-304	284.6	12.51	13	265-308	289.4	11.86	10	319-349	331.3	9.78	6.74	—	9.04
9. Rostrum tip to internal nares	mm	4	313-331	322.0	7.75	26	257-310	285.5	12.47	13	264-307	291.8	11.85	10	319-352	330.8	11.08	5.64	—	8.02
10. Preorbital width	mm	4	131-138	134.0	3.16	29	127-138	132.3	3.54	14	132-146	138.2	4.28	10	150-157	153.5	2.32	—	4.78	10.24
11. Postorbital width	mm	4	149-152	151.3	1.50	29	140-154	148.1	3.86	15	148-158	153.9	3.39	10	164-171	167.4	2.46	—	4.92	10.81
12. Least supraorbital width	mm	4	131-155	133.0	1.83	29	124-137	130.3	3.88	15	130-142	135.1	4.10	10	139-155	149.9	4.72	—	3.82	8.33
13. External nares width	mm	4	39-41	40.0	0.82	29	35-44	40.2	2.15	15	37-42	39.7	1.71	10	40-45	42.3	1.95	—	—	3.52
14. Zygomatic width	mm	4	149-152	150.5	1.29	29	139-153	146.4	3.68	14	145-158	152.9	3.57	10	159-171	165.4	4.14	2.18	5.48	7.92
15. Greatest width of premaxillaries	mm	4	61-66	64.0	2.16	29	49-67	60.6	3.34	15	58-66	62.1	2.03	10	64-72	67.4	2.37	—	—	5.98
16. Parietal width	mm	4	129-130	129.3	0.50	29	119-132	125.9	3.67	14	120-138	130.0	4.33	10	126-138	132.4	3.95	—	3.24	—
17. Braincase height	mm	4	85-89	86.5	1.91	29	83-92	86.4	2.35	14	80-95	89.4	3.39	9	86-98	92.1	4.34	—	3.39	—
18. Braincase length	mm	4	97-103	100.0	2.94	29	95-108	100.0	2.99	14	94-108	102.1	3.50	10	103-110	106.6	2.76	—	2.04	3.38
19. Posttemporal fossa length	mm	4	46-50	47.8	1.71	29	41-57	48.5	3.69	14	43-56	49.4	3.78	10	45-56	50.3	4.37	—	—	—
20. Posttemporal fossa width	mm	4	34-36	35.0	0.82	29	29-47	36.6	3.65	14	32-46	39.9	3.93	10	38-50	42.0	4.06	—	2.71	—
21. Temporal fossa major diameter	mm	4	30-34	32.5	1.73	27	28-34	30.6	1.74	14	28-35	31.1	2.25	10	33-37	35.3	1.34	—	—	5.26
22. Temporal fossa minor diameter	mm	4	18-23	20.0	2.16	27	15-23	20.2	1.80	14	16-24	21.0	2.11	10	23-27	25.0	1.25	—	—	5.34
23. Projection of premaxillaries	mm	1	—	17.0	—	14	13-25	18.3	3.20	3	15-22	18.0	3.61	4	22-30	24.8	3.59	—	—	2.47
24. Nasals to crest	mm	4	23-31	25.3	3.86	29	22-44	30.3	5.31	14	23-42	32.7	6.07	8	24-36	28.5	4.38	—	—	—
25. Orbit length	mm	4	40-44	41.8	1.71	29	38-43	39.8	1.61	15	37-44	40.6	1.80	10	42-47	44.2	1.81	2.31	—	4.89
26. Antorbital process length	mm	4	41-45	42.5	1.91	29	33-45	39.9	2.82	15	35-45	40.9	2.67	10	42-50	45.3	2.83	—	—	3.94
27. Internal nares width	mm	4	42-46	44.3	2.06	29	38-45	41.2	1.99	14	39-48	43.2	2.39	10	42-49	45.0	2.11	2.91	2.89	—
28. Pterygoid length	mm	4	54-63	58.8	4.03	29	45-63	55.6	4.38	13	53-62	57.4	2.87	10	58-68	61.9	3.31	—	—	3.49

29. Occipital overhang	mm	4	2-10	7.0	3.56	29	0-12	5.7	3.28	15	0-11	5.6	3.44	9	8-13	9.6	1.81	—	—	—
30. Bulla length	mm	0	—	—	—	23	25-29	27.6	0.94	15	26-30	28.1	1.05	7	28-31	29.8	1.04	—	—	3.54
31. Periotic length	mm	0	—	—	—	22	24-26	25.2	0.59	15	24-27	25.8	0.68	7	25-28	26.2	0.97	—	2.86	—
32. Upper tooth row length	mm	4	238-255	243.8	7.68	25	192-229	212.2	9.95	11	192-235	218.5	12.73	10	241-263	249.9	7.84	6.03	—	6.72
TEETH:																				
33. Upper left	no.	4	50-58	55.3	3.59	32	46-59	52.7	2.94	16	50-55	52.8	1.48	13	50-59	53.2	2.95	—	—	—
34. Upper right	no.	3	51-59	55.3	4.04	32	46-61	52.6	3.41	17	47-55	52.5	2.18	13	48-59	53.2	3.34	—	—	—
35. Lower left teeth	no.	4	52-59	56.3	2.99	34	45-56	50.8	2.28	16	47-54	51.1	1.81	13	48-55	51.8	1.79	4.43	—	—
36. Lower right teeth	no.	4	51-59	56.3	3.59	37	45-56	50.5	2.49	17	48-54	50-9	1.90	14	47-54	51.1	2.09	4.25	—	—
37. Lower tooth row length	mm	4	237-244	240.3	3.30	24	188-229	209.8	10.74	11	190-234	212.8	12.30	10	234-250	241.0	5.87	5.56	—	—
38. Ramus length	mm	4	358-378	367.3	8.30	27	301-348	329.1	12.28	15	308-360	335.1	13.11	10	365-399	379.4	10.64	5.98	—	8.89
39. Ramus height	mm	4	53-57	55.3	1.71	29	47-57	52.3	2.09	15	50-60	54.3	2.58	10	58-64	60.1	1.79	2.73	2.77	6.17
40. Mandibular fossa length	mm	4	87-98	93.5	4.80	27	78-97	86.9	4.81	15	79-97	89.9	5.11	10	88-108	98.5	6.26	2.56	—	3.77
41. Deviation from symmetry	degrees	4	6-9	7.8	1.26	29	4-13	8.3	1.98	14	6-13	8.4	2.06	9	8-15	11.1	2.47	—	—	2.84
42. Basihyal length	mm	4	27-34	31.5	3.11	23	20-33	28.5	3.01	14	25-32	29.3	2.19	5	28-32	29.8	1.48	—	—	—
43. Basihyal width	mm	4	31-36	33.5	2.08	22	25-40	33.5	3.69	15	29-37	34.4	2.06	5	34-38	36.2	1.48	—	—	—
44. Thyrohyal width	mm	4	16-21	19.0	2.16	23	9-21	16.5	2.82	15	15-23	17.8	2.11	5	13-21	17.6	2.97	—	—	—
45. Thyrohyal length	mm	4	45-50	46.8	2.36	23	28-58	43.1	6.37	15	42-29	44.5	2.42	5	42-48	45.0	2.24	—	—	—
46. Stylohyal width	mm	4	14-15	14.8	0.50	25	10-18	14.4	1.68	15	12-17	14.8	1.66	5	11-16	13.8	1.92	—	—	—
47. Stylohyal length	mm	4	65-66	65.5	0.58	25	51-69	61.6	4.65	15	55-71	64.8	3.65	5	64-77	67.0	5.61	—	—	—
48. Thoracic vertebrae	no.					16	14-17	15.4	0.72	19	14-16	15.5	0.61	2	14			—	—	
49. Lumbar vertebrae	no.					10	15-20	18.0	1.41	17	15-18	16.7	0.92					—	—	
50. Caudal vertebrae	no.					9	32-36	34.0	1.22	18	33-36	34.1	1.02					—	—	
51. Total vertebrae	no.					13	73-76	74.3	1.38	20	72-76	73.8	1.29	2	70-72			—	—	
52. Fused cervical vertebrae	no.					6	—	2.0	0	8	—	2	0	3	2			—	—	
53. Atlas width	mm					6	67-74	69.7	2.58	8	65-74	70.5	2.88					—	—	
54. Atlas height	mm					6	40-47	43.0	2.37	8	40-46	43.3	1.98					—	—	
55. Atlas lateral process length	mm					6	16-21	19.0	2.00	8	17-25	20.3	2.71					—	—	
56. Atlas neural spine length	mm					6	34-42	38.2	3.49	8	34-42	38.8	2.66					—	—	
57. Atlas dorsal ridge height	mm					6	1-2	1.3	0.53	8	1-2	1.3	0.46					—	—	
58. Atlas dorsolateral spine length	mm					6	0-1	0.5	0.55	8	0-4	1.4	1.41					—	—	
59. Axis lateral process length	mm					6	17-21	18.7	1.51	8	16-22	18.6	2.00					—	—	
60. Cervical vertebrae incomplete	no.					6	0	0.2	1.01	8	0-2	0.3	0.96	2	0			—	—	
61. Greatest ventrolateral cervical process	no.					5	5.5*6	5.9	1.14	8	—	6.0	0	2	6			—	—	
62. First vertical foramen on	no.					16	47-54	50.3	1.74	20	48-53	49.9	1.46	2	50			—	—	

*On nos. 5 and 6.

Table 19 (continued). Skeleton measurements and meristics of Costa Rican, eastern, whitebelly, and Hawaiian spinner porpoise, with statistical comparisons

Variable	Unit	A. Costa Rican				B. Eastern				C. Whitebelly				D. Hawaiian				Absolute value of significant t, at α = .05		
		Number of specimens	Range	Mean	Standard deviation	Number of specimens	Range	Mean	Standard deviation	Number of specimens	Range	Mean	Standard deviation	Number of specimens	Range	Mean	Standard deviation	A/B	B/C	C/D
63. First vertebra with reduced metapophyses	no.					14	27-33	30.1	1.79	20	27-33	30.5	1.72	2	31			—	—	
64. Last transverse process on	no.					15	56-59	56.8	0.94	20	55-58	56.5	0.83	2	54-55			—	—	
65. Last neural spine on	no.					16	61-65	62.0	1.10	20	60-63	61.6	0.94	2	59			—	—	
68. First caudal with vertical spine	no.					16	55-59	56.3	1.23	20	55-58	56.0	1.00	2	54			—	—	
69. First thoracic neural spine length	mm					6	12-22	16.7	4.13	8	16-28	23.3	4.06					—	2.99	
70. Second thoracic neural spine length	mm					6	33-38	35.8	1.83	8	34-42	38.0	2.78					—	—	
71. Tenth thoracic neural spine length	mm					6	54-58	56.0	1.41	8	53-61	56.5	2.45					—	—	
72. Last thoracic neural spine length	mm					6	57-65	62.7	3.14	7	61-68	65.3	2.21					—	—	
73. First thoracic vertebra height	mm					6	36-39	37.3	1.21	8	35-43	38.9	2.47				—	—		
74. First thoracic vertebra width	mm					6	67-80	72.5	4.72	8	66-77	72.5	3.55				—	—		
75. First lumbar vertebra height	mm					6	39-41	40.3	0.82	7	38-43	41.3	1.70				—	—		
76. First lumbar vertebra width	mm					6	162-171	166.0	3.58	8	162-171	166.8	3.58				—	—		
77. 23rd centrum length	mm					3	19-20	19.7	1.35	8	17-22	19.9	2.00				—	—		
78. Left vertebral ribs	no.					15	14-17	15.4	0.74	18	14-16	15.4	0.62	2	14		—	—		
79. Right vertebral ribs	no.					14	14-17	15.4	0.76	18	14-16	15.4	0.62	2	14		—	—		
80. Left 2-headed ribs	no.					18	5-7	5.4	0.61	20	5-7	5.5	0.69	2	5-7		—	—		
81. Right 2-headed ribs	no.					18	5-7	5.4	0.70	20	4-7	5.5	0.76	2	5-7		—	—		
82. Left floating ribs	no.					13	1-2	1.2	0.38	18	0-2	1.4	0.70	2	0		—	—		
83. Right floating ribs	no.					12	1-2	1.2	0.39	18	0-2	1.4	0.70	2	0		—	—		
84. Left sternal ribs	no.					15	8-11	9.3	0.80	19	8-11	9.6	0.76	2	9-10		—	—		
85. Right sternal ribs	no.					15	8-11	9.3	0.82	18	8-11	9.6	0.70	2	9		—	—		
86. First vertebral rib length	mm					6	90-105	96.8	5.56	8	96-113	104.1	5.19				—	—	2.53	
87. First vertebral rib width	mm					6	16-18	16.7	0.82	8	16-22	10.0	1.69				—	—	3.05	
88. Longest vertebral rib length	mm					6	217-229	222.8	5.00	8	228-261	243.1	9.77				—	—	4.62	
89. First sternal rib length	mm					6	64-72	68.8	2.64	8	65-73	70.6	2.77				—	—		

90. Manubrium width	mm					3	82-91	85.3	4.93	8	80-91	86.4	3.42				—	—		
91. Manubrium length	mm					5	47-57	53.2	4.27	8	46-63	54.5	5.04				—	—		
92. Manubrium notch depth	mm					5	6-10	8.4	1.67	8	77-11	8.6	1.51				—	—		
93. Manubrium foramen length	mm					5	0-10	2.8	4.09	8	0-1	0.8	0.46				—	—		
94. Mesosternal elements	mm					5	2-3	2.8	1.20	8	2-4	2.9	1.09	2	2		—	—		
95. Mesosternals fused	no.					5	1-3	2.0	1.00	8	1-3	2.0	0.53	2	0		—	—		
96. Chevron bones	no.					5	25-29	26.7	1.32	11	26-28	27.3	0.82				—	—		
97. Chevron bones fused in first series	no.					3	—	0	0	8	0-3	1.8	1.58				—	—		
98. First chevron on	no.					10	40-43	41.6	0.84	17	39-42	40.5	0.87				—	—	3.21	
99. Last chevron on	no.					11	64-70	66.9	1.87	13	65-68	67.1	0.95				—	—		
100. First chevron length	no.					3	5-12	7.7	3.79	8	8-12	9.9	1.55				—	—		
101. Longest chevron length	mm					6	39-46	43.2	2.93	8	38-46	42.8	2.43				—	—		
102. Last chevron length	mm					3	—	2.0	0	5	—	2.0	0				—	—		
103. Scapula height	mm					6	99-110	101.8	4.17	8	98-114	106.0	5.42				—	—		
104. Scapula length	mm					6	87-104	97.8	5.74	8	87-113	97.5	8.60				—	—		
105. Coracoid length	mm					6	28-54	36.3	9.00	8	30-39	33.8	3.37				—	—		
106. Coracoid width	mm					6	18-25	22.5	2.74	8	19-30	23.9	4.05				—	—		
107. Metacromion width	mm					6	35-57	44.3	7.55	7	29-48	41.9	6.49				—	—		
108. Humerus length	mm					6	43-47	45.2	1.33	8	44-50	47.3	2.12				—	—		
109. Humerus width	mm					6	31-37	34.5	2.26	8	33-40	36.3	2.49				—	—		
110. Radius length	mm					6	64-71	67.5	2.74	8	64-70	67.3	2.38				—	—		
111. Radius width	mm					6	31-36	32.7	1.75	8	31-35	33.4	1.39					—	—	
112. Ulna length	mm					6	54-61	56.7	2.50	8	54-60	57.3	2.12					—	—	
113. Carpal row width	mm					6	51-60	55.5	2.95	8	55-61	57.8	2.38					—	—	
PHALANGES:																				
114. Digit I	no.					17	—	0	0	19	—	0	0	1	0			—	—	
115. Digit II	no.					18	8-9	8.5	0.78	14	7-10	8.5	0.76	3	7			—	—	
116. Digit III	no.					17	5-7	6.2	1.87	14	5-7	6.1	0.66	2	5-6			—	—	
117. Digit IV	no.					15	2-3	2.5	0.84	14	2-3	2.8	0.43	0	—			—	—	
118. Digit V	no.					18	0-2	0.4	1.32	15	0-2	0.6	0.63	2	0-1			—	—	
119. Pelvic length (left) (M)	mm					4	69-81	72.5	7.37	3	68-74	71.3	—					—	—	
(F)	mm					2	42-60	—	—	5	53-62	57.6	—					—	—	
120. Pelvic length (right) (M)	mm					3	68-82	73.7	7.47	3	65-74	70.3	—					—	—	
(F)	mm					2	31-60	—	—	4	53-61	57.5	—					—	—	

Braincase. The Costa Rican series does not differ from the eastern series in size or shape of the braincase.

The means of the cranial dimensions of the whitebelly series are greater (at $\alpha = 0.05$) than those for the eastern series, but the differences are very small (4.1 mm, 3 mm, and 2.1 mm, for width, height, and length, respectively), and the series overlap nearly completely.

The whitebelly and Hawaiian series do not differ in breadth or height of the braincase and only slightly in braincase length.

Feeding apparatus. All four of the Costa Rican specimens possess longer rostra than any of the eastern specimens (fig. 81). The situation is different from that of the coastal spotted porpoise compared to the offshore form, in that the rostrum is not larger and more massive in the Costa Rican than in the eastern form, but only longer and more attenuate. The posttemporal fossae are not larger in Costa Rican specimens, indicating that jaw-closing musculature is not more developed in the longer-snouted animal. Width of the premaxillaries at midlength of the rostrum, and zygomatic width (nos. 6 and 14) are greater, but the overlap is extensive. The ramus is on the average higher (no. 40), but the disparity between means is very slight compared to that for ramus length, yielding a proportionately slenderer ramus. The longer feeding apparatus produces a change in overall proportions of the skull (fig. 81).

Tooth counts in the lower jaw (nos. 35 and 36) are on the average higher in the longer-snouted form, although individual variation in this character is wide, and the ranges overlap by about 50%. Further overlap might be expected were a larger sample of the Costa Rican form available.

The eastern and whitebelly series are very similar in size of the feeding apparatus and show no differences in proportions of the complex. The whitebelly skull is on the average slightly larger in some widths and heights in the feeding system (nos. 4, 11, 14, 20, 39), but the overlap is wide, and the differences disappear when the measurements are considered as percentage of condylobasal length or parietal width, indicating identity of proportion.

The Hawaiian spinner skull is strikingly larger than the whitebelly spinner skull in length and in facial breadth (figs. 76-80). The series do not overlap in the measurements of condylobasal length, rostrum length, rostrum tip to external and internal nares, preorbital and postorbital width, zygomatic width, length of upper tooth row, and length of ramus. The differences in length measurements reflect primarily differential development of the feeding apparatus of a different sort from that in the spotted porpoises, where the main component of geographical variation is in the area of origin of the temporal muscle (the "posttemporal fossa"). The Hawaiian and whitebelly series do not differ in dimensions of the muscle origin (nos. 19 and 20) but rather in the cross-sectional dimensions of the fossa proper (nos. 21 and 22). This is reflected also in the nonoverlap in postorbital and zygomatic widths. In a scatterplot of zygomatic width on ramus length (fig. 82), the Hawaiian series is clearly separable from the whiteblly series and even more different from the eastern and Costa Rica series. The Costa Rican specimens also have very long snouts but do not exhibit the increased massiveness of the posttemporal aspects of the feeding apparatus and the concomitant increased facial breadth. The relative positions of the Hawaiian and Costa Rican series in figure 82 demonstrate again that more than

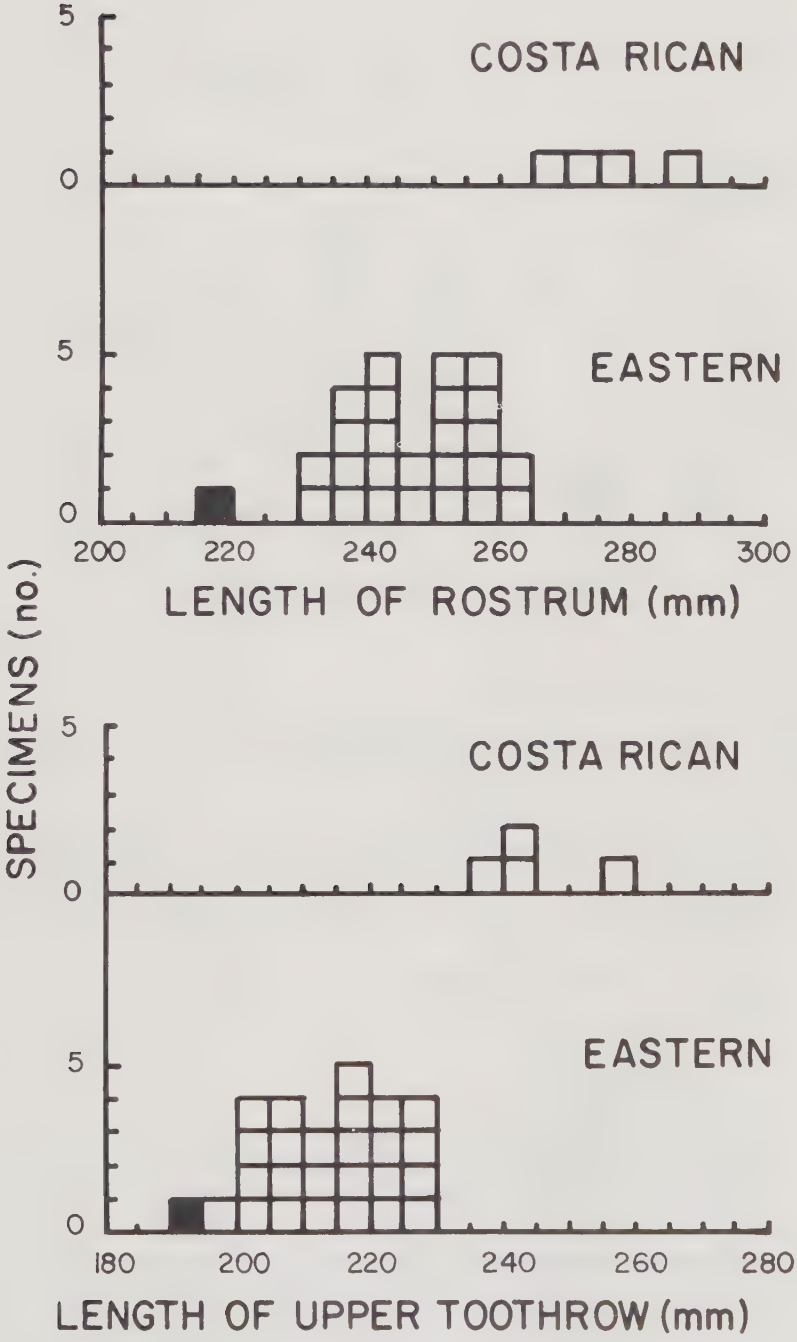

Figure 81. Geographical variation in skull measurements and proportions of spinner porpise, Costa Rican versus Eastern series: (top) length of rostrum (bottom) length of upper tooth row. Blackened square is infantile specimen discussed in text (continued).

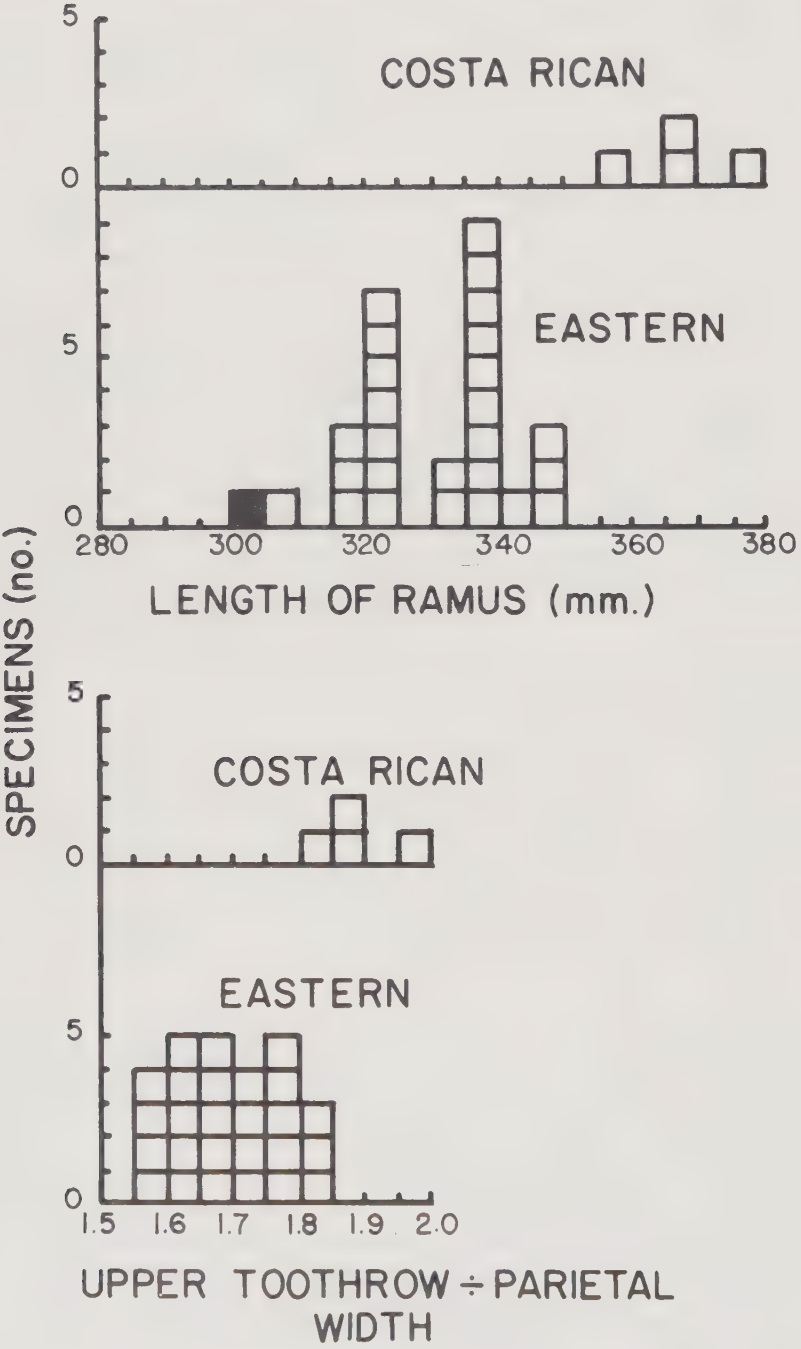

Figure 81 (continued). Geographical variation in skull measurements and proportions of spinner porpoise, Costa Rican versus Eastern series: (top) length of ramus, (bottom) relative length of tooth row. Blackened square is infantile specimen discussed in text.

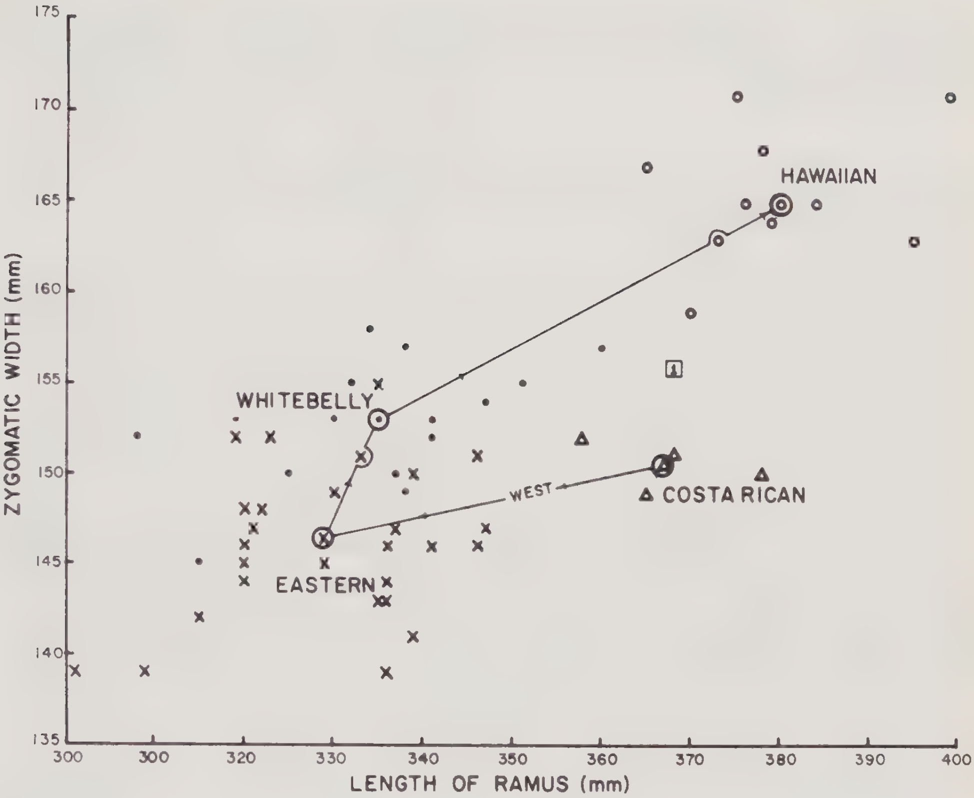

Figure 82. Geographical variation in the skull of the spinner porpoise in eastern tropical Pacific and Hawaiian waters: zygomatic width plotted on length of ramus. Circled symbols are series means. Square with numeral 1 is holotype of *S. longirostris* (Gray).

mere allometric growth is at work. The differing proportions must be responses to differential, and to some degree antagonistic, selection pressures on the various functional systems of the skull.

Vision apparatus. Mean orbit length in the Costa Rican series is slightly greater (2 mm) than in the eastern series, but overlap is nearly complete. The eastern, whitebelly, and Hawaiian series do not differ in size or proportions of the orbit.

Hearing apparatus. No ear bones are available for the Costa Rican forms. The whitebelly series exhibits mean periotic length 0.6 mm greater than that in the eastern series, but the ranges for the two series are nearly identical. The sample of ear bones from Hawaiian specimens is too small to allow comparison with the eastern Pacific forms.

Breathing and sound-producing apparatus. With the exception of a slightly greater average width of internal nares (no. 27), the Costa Rican and eastern series are not different in size and porportions of aspects of the breathing apparatus.

The eastern and whitebelly series are more divergent in proportions of the breathing and sound-producing system than in any of the other systems. All the widths encompassing the facial area are on the average greater in the whitebelly series, and the disparity in each case is greater than for condylobasal length (or, more precisely, CB length minus rostrum length), indicating proportional difference.

The Hawaiian form is broader facially than the whitebelly form.

Summary. The Costa Rican and eastern series are very different in size and proportions of the feeding apparatus but very similar in the other systems. The longer, more attenuate beak of the Costa Rican form is presumably an adaptation to local feeding conditions or prey items. The eastern and whitebelly series are very similar in size and proportions, with some slight divergence in proportions of the facial area in the hearing and sound-producing complex. The differences between these two series are slight indeed compared to those between the eastern and Costa Rican series or the whitebelly and Hawaiian series. The Hawaiian series diverges sharply from the whitebelly series in size of the feeding apparatus.

Postcranial skeleton

The sample for postcranial measurements is limited to physically mature specimens. No postcranial skeletons are available for the Costa Rican form and only 4 were available from Hawaii.

The mean values in the whitebelly series are greater than in the eastern series in length of the first thoracic neural spine (no. 69), length and width of the first vertebral rib (nos. 86 and 87), and length of the longest vertebral rib (no. 88). In length of the longest rib the two series very nearly do not overlap. In postcranial meristics, the eastern Pacific series differ only in placement of the first chevron bone, with an average difference of about one vertebra. Only 2 Hawaiian skeletons were sufficiently complete to allow collection of meristic data. The two had 70 and 72 vertebrae as opposed to the ranges of

72-76 for 20 whitebelly spinners, and 73-76 for 13 eastern spinners, indicating that the Hawaiian form may have fewer vertebrae than spinners in the eastern Pacific. The difference is in the precaudal series, as indicated by the positions of the first vertical foramen, last transverse process, and last neural process.

CLASSIFICATION AND DIAGNOSES

I conclude on the basis of the above evidence that the spinners of eastern Pacific and Hawaiian waters belong to a single geographically variable species. The name that should apply to this species is still a matter of question, for the reasons discussed above, but I provisionally use *Stenella longirostris* (Schlegel, 1841). The holotype of this species is from an unknown locality and does not fit well into the ranges of cranial measurements of any of the four geographical races defined above (fig. 82); therefore, the final disposition and nomenclature of the forms studied here must await the results of further discriminant analyses based on series covering more of the pantropical distribution of the spinners.

The four geographical races deserve subspecific status. The Costa Rican and Hawaiian series are separable from the eastern and whitebelly series, but I do not elevate the populations to specific rank because the series of adult skeletal specimens studied are quite small (4 and 10, respectively). The group of whitebelly specimens (24) for which color pattern data were available, moreover, is not sufficiently large to convince me that intergradation may not be encountered in larger series. The forms are very similar in cranial features, and even with discriminant analysis skeletal specimens can be separated only with 91% accuracy (table 20 and fig. 83). I therefore designate these forms also as subspecies only.

While the type of *D. longirostris* Schlegel obviously does not belong to the same subspecies as the eastern or whitebelly series (it may fall into the extremes of the Costa Rican or Hawaiian ranges), it is possible that further discriminant analyses may assign the types of *D. microps* Gray, *D. stenorhynchus* Gray, or *D. alope* Gray to one or the other of them, along with the names. I therefore do not name any of the four subspecies but designate them only as *S. longirostris* subspecies A, B, C, and D, recognizing that one of them (A or D) may be the type subspecies, and that applicable names may already exist for the subspecific portions of the trinomials for all or some of them.

Diagnoses of Subspecies of Spinner Porpoise, *Stenella longirostris* (Schlegel, 1841), of the Eastern Pacific and Hawaii

A. Costa Rican Spinner Porpoise, *Stenella longirostris* subsp. A (unnamed?).

Coloration. Poorly known, probably similar to that described by Perrin (1972) for the "eastern form" (B below).

External size and shape (based on 4 specimens). Adults 1.8-2.2 m long; tip of snout to apex of melon 14-17 cm, to flipper origin 44-47 cm, to dorsal fin tip 94-101 cm (46-53% body length); girth at axilla 69-77 cm (32-40% body length).

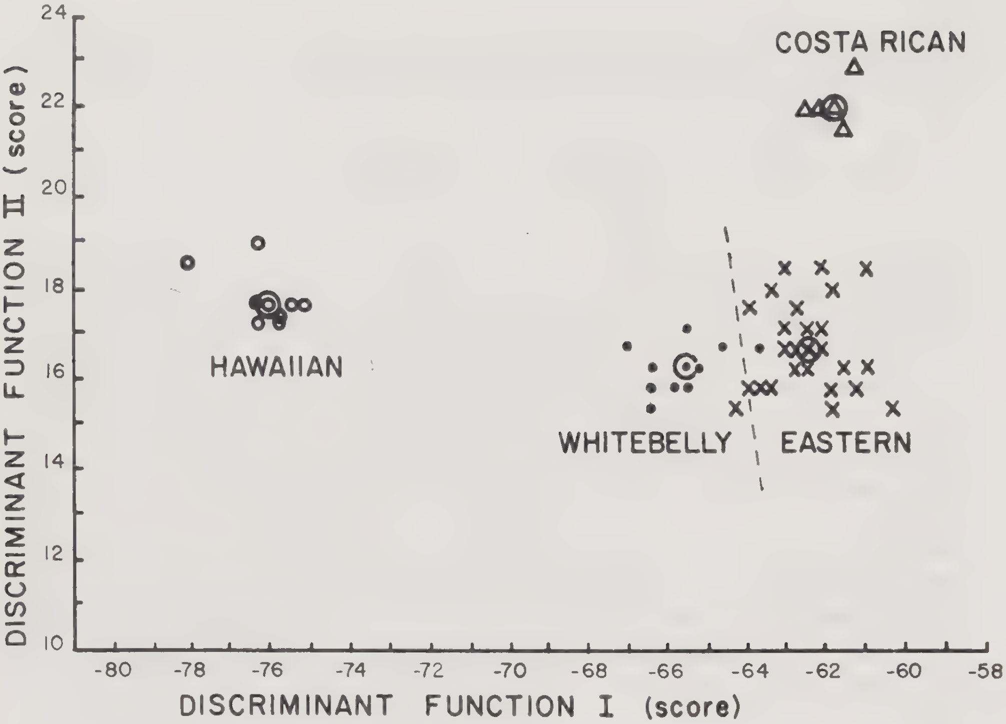

Figure 83. Geographical series of skeletal specimens of spinner porpoise plotted on first three discriminant functions (based on 25 measurements). Circled symbols are series means.

Skeleton. Condylobasal length 416-437 mm; rostrum length 269-288 mm (208-223% parietal width); rostrum width at base 70-77 mm; tip of rostrum to external nares 313-331 mm (75-80% CB length, 244-260% parietal width); postorbital width 149-152 mm (115-118% parietal width); major diameter of temporal fossa 30-34 mm, minor diameter 18-23 mm; length of upper tooth row 238-255 mm (185-198% parietal width); length of ramus 358-378 mm (278-293% parietal width); tooth counts $\frac{50-59}{51-59}$; no information on postcranial skeleton.

Range. Nearshore waters of Pacific coast of Central America. Recorded only from Costa Rica and El Salvador.

B. Eastern Pacific Spinner Porpoise, *Stenella longirostris* subsp. B (unnamed?).

Coloration. As described by Perrin (1972) for "eastern spinner."

External size and shape. Adults 1.6-1.9 m long, tip of snout to apex of melon 11-15 cm, to flipper origin 36-43 cm, to dorsal fin tip 83-95 cm in males (49-56% body length) and 85-101 cm in females (48-50% body length); girth at axilla 68-80 cm (40-49% body length). Canted fin and ventral hump as described by Perrin (1972 and above).

Table 20. Loading coefficients for first two discriminant functions separating Costa Rican, Eastern, Whitebelly, and Hawaiian series of crania of spinner porpoise. Measurements refer to figure 2

Number	Measurement	Discriminant Function I	Discriminant Function II
1	Condylobasal length	-.12411	-.04808
2	Length of rostrum	-.20709	-.16605
3	Width of rostrum at base	-.00716	-.00775
4	Width of rostrum at 60 mm	.49906	.32805
5	Width of rostrum at midlength	-.77836	-.45203
6	Width of premaxillaries at midlength of rostrum	.76464	.50564
7	Width of rostrum at 3/4 length	.73873	.19535
8	Tip of rostrum to external nares	.01450	.09391
9	Tip of rostrum to internal nares	.10828	.12807
10	Preorbital width	-.86583	-.17570
11	Postorbital width	.78164	.14861
12	Least supraorbital width	.20805	.00969
13	Width of external nares	-.08184	-.07997
14	Zygomatic width	-.72493	-.12731
15	Greatest width of premaxillaries	.32605	.14079
16	Parietal width	-.10273	-.00481
17	Height of braincase	.09109	.19587
18	Length of braincase	.06318	-.05494
19	Length of posttemporal fossa	-.07131	-.22892
20	Width of posttemporal fossa	-.06509	-.11738
25	Length of orbit	-.70907	-.11276
27	Width of internal nares	.20716	.11607
32	Length of upper tooth row	.23194	.05071
38	Length of ramus	.00695	.02887
39	Height of ramus	.10282	-.03908

Skeleton. Condylobasal length 351-407 mm; rostrum length 218-262 mm (180-213% parietal width); rostrum width at base 66-77 mm, tip of rostrum to external nares 252-304 mm (72-76% CB length, 208-246% parietal width); postorbital width 140-154 mm (110-124% parietal width); zygomatic width 139-153 mm (35-41% CB length, 109-123% parietal width); major diameter of temporal fossa 28-34 mm, minor diameter 15-23 mm; length of upper tooth row 192-229 mm (157-184% parietal width); length of ramus 301-348 mm (244-284% parietal width); tooth counts $\frac{46-61}{45-56}$; length of longest vertebral rib 217-229 mm; 73-76 vertebrae.

Range. Pacific coast of tropical North American from Tres Marias Islands south at least to Acapulco, and offshore approximately 800 km. Replaced on coast of Central America by the Costa Rican spinner (A, above).

This is the eastern Pacific form described or referred to (variously as *microps*) in Dailey and Brownell (1972), Daugherty (1966), Evans (1967), Evans, Sutherland, and Bell (1964), Fitch and Brownell (1968), Harrison (1969*a*, 1969*b*), Harrison, Boice, and Brownell (1969*b*), Harrison, Johnson, and Tedder (1967), Harrison, Johnson, and Young (1970), Hershkovitz (1966), Hester, Hunter, and Whitney (1963), Miller (1924), Miller and Kellogg (1955), Nelson (1899), Nishiwaki (1967 and 1972), Norris (1967), Perrin (1968, 1969, 1970*a*), Pilson and Waller (1970), Purves (1969), Rice (1967), Rice and Scheffer (1968), Scheffer and Rice (1963), True (1889), Van Gelder (1960) and Walker (1964).

C. Whitebelly Spinner Porpoise, *Stenella longirostris* subsp. C (unnamed?).

Coloration. As described by Perrin (1972).

External size and shape. Adults 1.6-1.9 m long; tip of snout to apex of melon 13-15 cm, to flipper origin 39-44 cm, to dorsal fin tip 91-102 cm (53-58% body length); girth at axilla 75-87 cm (43-52% of body length). Triangular fin and ventral hump as described by Perrin (1972 and above).

Skeleton. Condylobasal length 365-419 mm; rostrum length 227-271 mm (175-217% parietal width) rostrum width at base 69-78 mm; tip of rostrum to external nares 265-308 mm (71-75% CB length, 204-250% parietal width); postorbital width 148-158 mm (114-126% parietal width); zygomatic width 145-158 mm (37-42% CB length, 112-124% parietal width); major diameter of temporal fossa 28-35 mm; minor diameter 16-24 mm; length of upper tooth row 192-235 mm (148-189% parietal width); length of ramus 308-360 mm (237-282% parietal width); tooth counts $\frac{47-55}{47-54}$; length of longest vertebral rib 228-261 mm; 72-76 vertebrae.

Range. Far offshore tropical waters of eastern Pacific from approximately 800 km offshore to 140°W longitude.

This form has been previously described or referred to only in Perrin (1972) and Dailey and Perrin (1973).

D. Hawaiian Spinner Porpoise, *Stenella longirostris* subsp. D (unnamed?).

Coloration. As described by Perrin (1972).

External size and shape. Adults $\geqslant$ 1.7-2.0 m long; tip of snout to apex of melon 17-19 cm, to flipper origin 42-51 cm, to dorsal fin tip 103-117 cm (58-60% body length); girth at axilla 71-86 cm (38-48% body length). Dorsal fin falcate, ventral hump absent except for slight development in large males.

Skeleton. Condylobasal length 431-464 mm; rostrum length 277-304 mm (206-241% parietal width); rostrum width at base 76-84 mm, tip of rostrum to external nares 319-349 mm (74-77% CB length, 238-277% parietal width); postorbital width 164-171 mm (122-130% parietal width); zygomatic width 159-171 mm (35-39% CB length, 119-130% parietal width); major diameter of temporal fossa 33-37 mm; minor diameter 23-27 mm; length of upper tooth row 241-263 mm (180-208% parietal width); length of ramus 365-399 mm (272-314% parietal width); tooth counts $\frac{48-59}{47-55}$; number of vertebrae 70-70 (2 specimens); no postcranial measurements available for physically mature specimens.

Range. Hawaiian waters. Specimens from Hawaiian waters that are referred in the literature to *Stenella longirostris* or *Stenella roseiventris* are of this subspecies.

Specimens from unknown localities in the eastern Pacific may also be classified by application of the discriminant functions in table 20 and comparisons of the scores with the scatterplot in figure 83.

Summary of Differences between the Subspecies

The Costa Rican form is longer and more attenuate, and has a proportionately longer, narrower skull than do the other three forms. The Hawaiian form is distinctive in its large, broad skull and sharply defined, tripartite color pattern. The eastern and whitebelly forms both have small skulls of intermediate breadth, but sharply different color patterns. The eastern form is largely dark, whereas the whitebelly form presents a two-tone appearance. The whitebelly form is also slightly more robust than the eastern form, and the correlated extreme development of ventral hump and forward cant of dorsal fin that is typical of adult eastern males is absent.

GENERAL CONCLUSIONS

Some generalizations relevant to the systematics of delphinids in general can be drawn on the basis of this examination of variation in *Stenella.*

1. Sharp geographical differentiation is to be expected over quite short distances, that is, hundreds or even tens of kilometers. In addition, less pronounced clinal variation is to be expected within the ranges of well-defined races.
2. Before progress can be made in revising any delphinid group (species, superspecies, genus), thorough studies must be made of variation owing to ontogeny, sexual dimorphism, and individual variability in that particular group. Few prior assumptions can be made about the sources of variation. This is demonstrated by the sharp differences in the patterns of variation of the two species studied here. For example, the spinner porpoise is sharply dimorphic in external proportions but only slightly so in skeletal features, whereas the exact opposite is true for the spotted porpoise. The spinner skull develops faster than the skull of the spotted porpoise. Patterns of relative growth of external features, for example, the flukes, differ sharply between the two species. The results of this study of large series are an adequate basis for evaluating variation in smaller series of the same two species from other parts of the world, but not necessarily for evaluation of geographical variation in series of other forms of other genera, for example, *Delphinus* or *Tursiops.*
3. The above caveat notwithstanding, some general tendencies in geographical variation are apparent. The rostrum and temporal fossae, that is, the feeding apparatus, vary most sharply in both forms studied, whereas the braincase varies least. Localized races with long versus short or with robust versus narrow snouts should be expected in other delphinid groups. Overall body size should also be expected to vary sharply over short distances.

SUMMARY

1. Spotted porpoise occur in coastal and offshore tropical waters in a triangularly shaped area of the eastern Pacific and in Hawaiian waters. The base of the triangle is the coastline from Cabo San Lucas, Mexico to Colombia, and the seaward apex is at about 10°N latitude, 145°W longitude.

2. Intensity of spotting varies along an east-west axis in the eastern Pacific. Coastal animals on the average are most heavily spotted, and those from the westernmost parts of the range are least spotted. Hawaiian animals are unspotted or sparsely spotted as adults.

3. Changes in external proportions of the spotted porpoise during development are owing primarily to a disproportionate rate of growth of the section of torso between the umbilicus and anus, combined with an early surge in growth of the snout. The snout apparently stops growing at puberty, but total body length continues to increase at least until the onset of physical maturity.

4. Adult female spotted porpoise average about 10 cm smaller than males but have relatively longer snouts, greater girth, and greater fluke span.

5. Individual variation in external proportions of the spotted porpoise is greatest in length of the snout. Of the appendages, the dorsal fin is most variable.

6. Spotted porpoise from very near the coast are larger than offshore specimens in all torso dimensions and in fluke span. The offshore animals have longer flippers. The Hawaiian form has a larger head than the offshore form.

7. The functional systems of the spotted porpoise skull have different patterns of postnatal development. The hearing apparatus is most precocious, followed by the vision apparatus, the braincase, the breathing and sound-producing apparatus, and the feeding apparatus, in that order. Skulls with 5 or more layers in the postnatal dentine can be considered "adult" for purposes of inclusion in taxonomic series.

8. The postcranial skeleton of the spotted porpoise develops more slowly than the skull, with the exception of its anteriormost elements. The scapula, vertebral centra, and long vertebral ribs show most protracted growth.

9. The sex of a spotted porpoise can be determined from measurements of the skull only if the specimen is physically mature. In general, males have larger braincases and shorter, broader rostra.

10. Individual variation in the skull of the spotted porpoise is greatest in the feeding apparatus, closely followed by the breathing and sound-producing apparatus. The remaining functional units of the skull are significantly less variable.

11. Geographical variation in the skeleton of the spotted porpoise indicates existence of distinct coastal and offshore forms. This confirms the results of the analysis of external size and shape. Of the functional systems of the skull, the two series are most disparate in the feeding apparatus, the offshore form having a shorter, more attenuate rostrum. Differences are smallest in the braincase. The coastal form is also larger in most postcranial measurements, but has on the average fewer vertebrae. Within the offshore series, there is an apparent east-west cline in absolute size; the most offshore animals are the largest. The Hawaiian spotted porpoise has a slightly greater parietal width, larger feeding apparatus, and more massive postcranial skeleton than the offshore form.

12. The taxonomy of the spotted porpoise is confused, but there appears to be only a single species in the Pacific. The name *Stenella attenuata* (Gray, 1846) is provisionally used for this species.

13. The eastern Pacific coastal, eastern Pacific offshore, and Hawaiian spotted porpoise deserve subspecific status within *Stenella attenuata.* Because many of the holotypes of spotted porpoise are from unknown localities, a trinomial can presently be assigned only to the coastal form, namely, *S. attenuata graffmani.* Skulls of unknown provenance within eastern Pacific and Hawaiian waters can be referred to one of the four forms with the help of discriminant functions.

14. The range of spinner porpoise in the eastern Pacific coincides that of the spotted porpoise almost exactly.

15. Patterns of developmental, sexual, and individual external variation differ between the spinner porpoise and the spotted porpoise. Attenuation in spinners is less during postpubertal development than in the spotted porpoise. Adults have proportionately larger appendages than juveniles. The dorsal fin is canted forward to varying degree in large males. Males and females do not differ in proportionate girth or size of appendages.

16. In external size and shape, as well as in coloration, the eastern Pacific specimens fall into three geographical series. "Costa Rican" (coast of Central America) spinners are longest and most attenuate. "Eastern" spinners (North American coast to about 800 km offshore) are greatest in girth and have the least canted dorsal fins. The Hawaiian spinner has a color pattern most like that of the whitebelly form but is larger.

17. The skeleton of the spinner porpoise develops in the same pattern as that of the spotted porpoise, except that cranial development proceeds more rapidly. The adult configuration is reached when 4 layers have been laid down in the dentine, and postpubertal elongation of the axial skeleton is less protracted, rendering overall growth more isogonic. Sexual dimorphism is negligible. Patterns of individual variation are similar to those in the spotted porpoise.

18. In skeletal features, the Costa Rican spinner is most divergent, having a very long, attenuate rostrurn. Differences between the eastern and whitebelly series are comparatively slight. The Hawaiian spinner has a longer, broader skull than the eastern Pacific forms.

19. Taxonomy of the spinner porpoise is as confused as that of the spotted porpoise , but again there appears to be but a single species in the Pacific. The name *Stenella longirostris* (Schlegel,1841) is applied provisionally.

20. The Costa Rican, eastern, whitebelly, and Hawaiian spinners deserve subspecific status within *S. longirostris,* but trinomials cannot be assigned until the taxonomy has been adequately reviewed on a worldwide basis. Skulls of unknown provenance can be classified with discriminant functions.

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THE ROUGH-TOOTHED PORPOISE, *STENO BREDANENSIS*, IN THE EASTERN TROPICAL PACIFIC

The rough-toothed porpoise, *Steno bredanensis* (Lesson), is common in Hawaiian waters (Tomich, 1969; Norris, 1974), but has only been recorded twice from the eastern Pacific. A weathered skull was collected on the beach in Marin County, California, in 1946 (Orr, 1951), and a skull with mandible, 12 vertebrae, and one rib were found on Isla Santa Cruz, Archipiélago de Colon (Galapagos Islands) in 1964 (Orr, 1965). The purpose of this note is to report four additional records, all based on captures, that firmly establish the species as a member of the tropical fauna of the eastern Pacific.

On 4 May 1971, a tuna seiner captured a 212-centimeter female in a net set on a mixed herd of spotted porpoise, *Stenella attenuata* (Gray), and spinner porpoise, *S. longirostris*

(Gray), at 7°12′ N latitude, 90°11′ W longitude. Kenneth Brumley, chief engineer of the vessel, had previously been asked by one of us (Walker) to collect uncommon cetaceans that he encountered in the tuna fishery. He measured the specimen and collected and froze the head, one flipper and the flukes. The prepared skull and flipper and photographs and external measurements of the head, flipper, and flukes have been deposited in the U.S. National Museum, Washington, D.C. (USNM 504,113). The statement by Leatherwood *et al* (1972) that "several [rough-toothed porpoise] were recently collected near Clipperton Island" refers to this previously unpublished record.

On 10 February 1974, at 14°36′ N latitude, 104°19′ W longitude, three to four rough-toothed porpoise together with about 300 spotted porpoise were captured by a purse seiner. Gordon M. Armstrong, a National Marine Fisheries Service observer on the vessel, identified the animals in the water from the diagnostic large eyes and flippers and lack of demarcation between the long beak and the melon. They remained in a tight group, diving and circling in the net together with the spotted porpoise. They were released from the seine unharmed during the porpoise-rescue maneuver called "backing down" (operation described in Perrin, 1968). Armstrong assisted one individual over the corkline and thus got a close look at it. Fifteen tons of yellowfin tuna, *Thunnus albacares* Bonnaterre, were captured. The sea surface temperature was 27° C.

The same vessel subsequently encountered *Steno* again on the same cruise, at 14°22′ N latitude, 102°40′ W longitude on 22 February 1974. The net was set on approximately 400 spotted porpoise and 40 bottlenose porpoise (*Tursiops* sp.). One rough-toothed porpoise is known to have died in the net and was retrieved. No others were positively identified in the water, although some of the animals released alive from the net and thought to be *Tursiops* may have been *Steno*. Twenty-five tons of yellowfin tuna were captured. The sea surface temperature was 28° C. The specimen, a 216-centimeter male (length measured from tip of upper jaw to base of notch in flukes) weighing 114 kilograms, was frozen in the vessel's fish hold and subsequently shipped frozen to the U.S. National Museum, where it was photographed, measured, and preserved entire (USNM 504,092) after the testes and stomach had been removed. The left and right testes measured 37.0 by 10.0 by 7.5 and 39.0 by 11.0 by 7.5 centimeters, respectively. The stomach contained remains of molluscs and fish, which were preserved for later identification.

On 15 February 1974, at 10°13′ N latitude, 91°30′ W longitude, another tuna seiner captured approximately 10 rough-toothed porpoise with about 1800 spinner porpoise and 200 spotted porpoise. A National Marine Fisheries Service observer aboard, Thomas Duffy, collected the head and stomach of a 189-centimeter male that died in the set. Ninety tons of yellowfin tuna were captured in the set. The sea surface temperature was 27° C. The frozen *Steno* head was forwarded to the U.S. National Museum, where the skull was prepared and placed in the collection (USNM 504,089). The stomach contents have not yet been examined.

Acknowledgments.—We thank the owners, captains, and crews of the *Polaris, Margaret L.*, and *Marietta* for their cooperation, and Kenneth Brumley, Gordon M. Armstrong, and Thomas Duffy for permission to publish their observations. James G. Mead very kindly supplied data for the specimens shipped to the U.S. National Museum.

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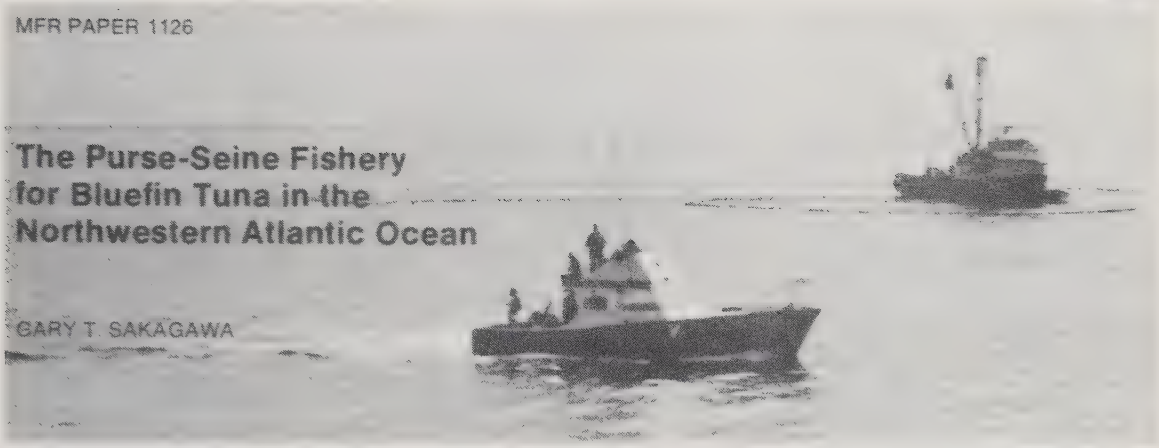

The Purse-Seine Fishery for Bluefin Tuna in the Northwestern Atlantic Ocean

GARY T. SAKAGAWA

Purse seining by commercial fishermen and trolling by recreational fishermen for bluefin tuna off the east coast of the United States. U.S. commercial and recreational fishermen compete for bluefin tuna during the summer and fall months offshore from New Jersey to Maine.

ABSTRACT—The history of the purse-seine fishery for bluefin tuna in the northwestern Atlantic Ocean is reviewed, and events that contributed to fluctuation of the catch are discussed. The fishery began in 1958 and produced 5,770 mt (metric tons) at its peak in 1963. The catch declined from 4,290 mt in 1970 to about 1,780 mt in 1973. The 1973 catch was landed by a fleet with about 4,900 mt carrying capacity, which was in excess of the catch. Average length of bluefin tuna in the purse-seine catch decreased from about 140 cm in 1960 to about 89 cm in 1973, owing in part to a southward expansion of the fishing grounds into areas where small bluefin tuna are more available. Prior to 1962, the fishing grounds were centered in Cape Cod Bay. Currently it is centered off New Jersey-New York. The nominal catch rate of Class 3 seiners has fluctuated, but it appears that the prevailing trend in the 1970's is downward with the current rate at a low level.

INTRODUCTION

The northern bluefin tuna (*Thunnus thynnus thynnus*) was considered a nuisance by U.S. fishermen of the Atlantic coast until at about the turn of this century a domestic market was developed, first for the oil then only for the meat (Bigelow and Schroeder, 1953). Traps, harpoons, and handlines were the primary gear used to catch bluefin tuna in the northwestern Atlantic before 1958. The total Canada-U.S. catch averaged about 900 tons[1] annually in 1942-57. In 1958, purse-seine fishing was introduced (Squire, 1959; Wilson, 1965), and the total catch (all gear) increased to an average of 2,800 tons annually (Fig. 1), but the catch has fluctuated considerably. In fact, the total catch since 1969 declined from 4,800 tons in 1970 to 2,400 tons in 1972. This report reviews the development of the purse-seine fishery for bluefin tuna in the northwestern Atlantic and describes some events that had a bearing on fluctuation of the catch.

THE FISHERY

Canada and the United States are the only participants in the purse-seine fishery for bluefin tuna in the northwestern Atlantic Ocean. As early as 1937 purse seines were experimentally used to catch bluefin tuna in the northwestern Atlantic (Murray, 1952). However, the fishery, as we know it today, essentially began in 1958 when the *Silver Mink*, a 41-ton carrying capacity U.S. purse seiner, demonstrated in Cape Cod Bay, Mass. that bluefin tuna could be caught commercially (Squire, 1959; Wilson, 1965). From 1958 to about 1962 only small, U.S. seiners (<92 tons carrying capacity), based in New England ports, participated in the fishery, which was centered in Cape Cod Bay. In 1962, the fishery expanded southward as far as North Carolina (Wilson, 1965). In 1963, Canadian seiners (100 tons capacity) and large, California- and Puerto Rico-based seiners (>363 tons capacity) entered the fishery. These

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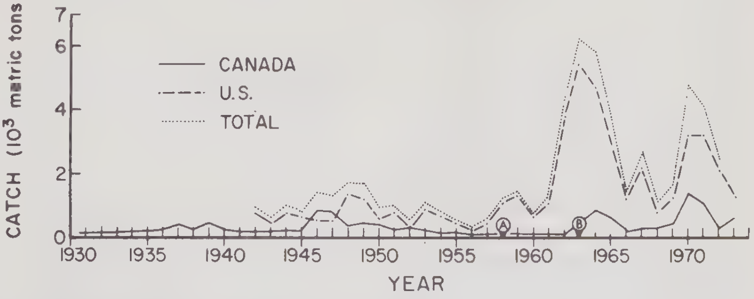

Figure 1.—Canadian and U.S. commercial catch of bluefin tuna from the Atlantic Ocean: A, the year 1958 when the purse-seine fishery first started; B, the year 1963 when large seiners (>181 tons capacity) first entered the fishery. The 1973 catches are preliminary and only includes purse-seine catches.

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[1] Tons refer to metric tons in this report.

events transformed the fishery into one with cosmopolitan participation with vessels fishing for bluefin tuna as well as the tropical tunas, yellowfin (*T. albacares*) and skipjack (*Katsuwonus pelamis*), that occur in fishable quantities in some years off the east coast of the United States (Wilson, 1965).

Unlike the trap, harpoon, and handline fisheries that generally catch large bluefin tuna (>122 cm long[2]), the purse-seine fishery primarily catches schooled bluefin tuna, 50-122 cm long, which are sold to canneries for processing into canned tuna. Fish larger than about 140 cm long are generally undesirable for canning and are sold to fresh-fish markets. (Currently, Japan is an important market for the large fish.) In any one year, not more than about 16 percent of the purse-seine catch, in weight, has been large bluefin tuna.

The purse-seine fishery operates within a narrow belt that extends about 220 km from the coast. Fishermen claim that not many schools are found beyond that region. Mather and Schuck[3] indicated that schooled bluefin tuna are found in the northwestern Atlantic between Cape Charles, Va. and Newfoundland, but primarily between Cape Charles and Cape Cod, Mass.

Through the years the use of land-based aircraft to assist seine fishermen in locating and setting on schools of bluefin tuna has become popular. Virtually all the small seiners and some large seiners currently use aircraft in fishing operations. The technique is quite effective in that it increases the searching range and fishing success of the vessels. This is probably a major factor contributing to the ability of the small vessels to consistently catch a large share of bluefin tuna from the northwestern Atlantic (Sakagawa and Coan[4]).

TOTAL CATCH

The total Canadian-U.S. landings (all gear) of bluefin tuna from the northwest Atlantic historically fluctuated around 900 tons annually until 3 years after the purse-seine fishery became established in 1958 (Fig. 1). The total landings then increased sharply from 1,200 tons in 1961 to

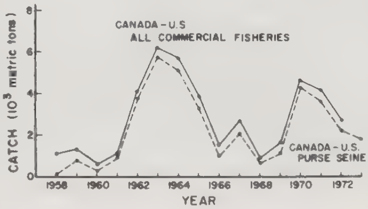

Figure 2.—Total Canada-U.S. commercial catch of Atlantic bluefin tuna by the purse-seine fishery.

Table 1.—Purse-seine catches (Canadian and U.S. combined) of bluefin and skipjack tuna in the northwestern Atlantic Ocean, 1958-73.

Year	Number of seiners	Catch (metric tons)		
		Bluefin[1]	Skipjack[2]	Total
1958	1	138	0	138
1959	1	781	0	781
1960	1	277	0	277
1961	2	903	0	903
1962	7	3,767	434	4,201
1963	18	5,770	2,899	8,669
1964	21	5,167	4,974	10,141
1965	13	3,331	179[3]	3,510
1966	7	1,006	149[3]	1,155
1967	11	2,083	3	2,086
1968	5	688	2[3]	690
1969	4	1,118	103[3]	1,221
1970	8	4,287	650[3]	4,937
1971	12	3,825	610[3]	4,435
1972	11	2,137	44[3]	2,181
1973	7	1,781[4]	35[4]	1.816[4]

[1] Sources: Aloncle et al (1972), Fishery Statistics of the United States (1960-69, 1971-73) and Statistics and Market News Division, National Marine Fisheries Service, Washington, DC 20235. Virtually all bluefin tuna are landed in the year caught, and landings are considered catches in this report.

[2] Estimated catch statistics from Mather, F. J. III, Woods Hole Oceanographic Institution, Woods Hole, MA 02543 (pers. commun.) except those from logbooks (see footnote 3).

[3] Estimates from logbooks.

[4] Preliminary estimates.

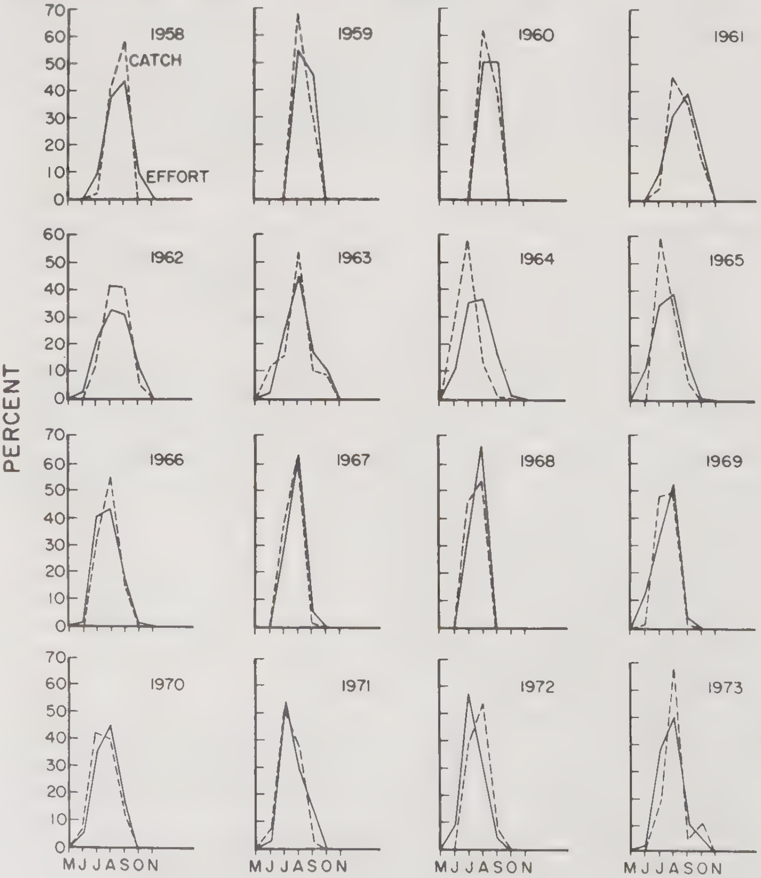

Figure 3.—Percent distribution of catch of bluefin tuna and fishing effort for purse seiners participating in the bluefin tuna fishery of the northwestern Atlantic.

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[2] Length measurements are straight line distances from tip of snout to fork of tail.

[3] Mather, F. J. III, and H. A. Schuck. Contribution to the biology of the bluefin tuna (*Thunnus thynnus*) of the western North Atlantic. Part I. Age and growth, distribution, and migrations. Manuscript, 177 p. Woods Hole Oceanographic Institution, Woods Hole, Massachusetts 02543.

[4] Sakagawa, G. T., and A. L. Coan. A review of some aspects of the bluefin tuna (*Thynnus thynnus thynnus*) fisheries of the Atlantic Ocean. Manuscript, 83 p. National Marine Fisheries Service, Southwest Fisheries Center, La Jolla, California 92037.

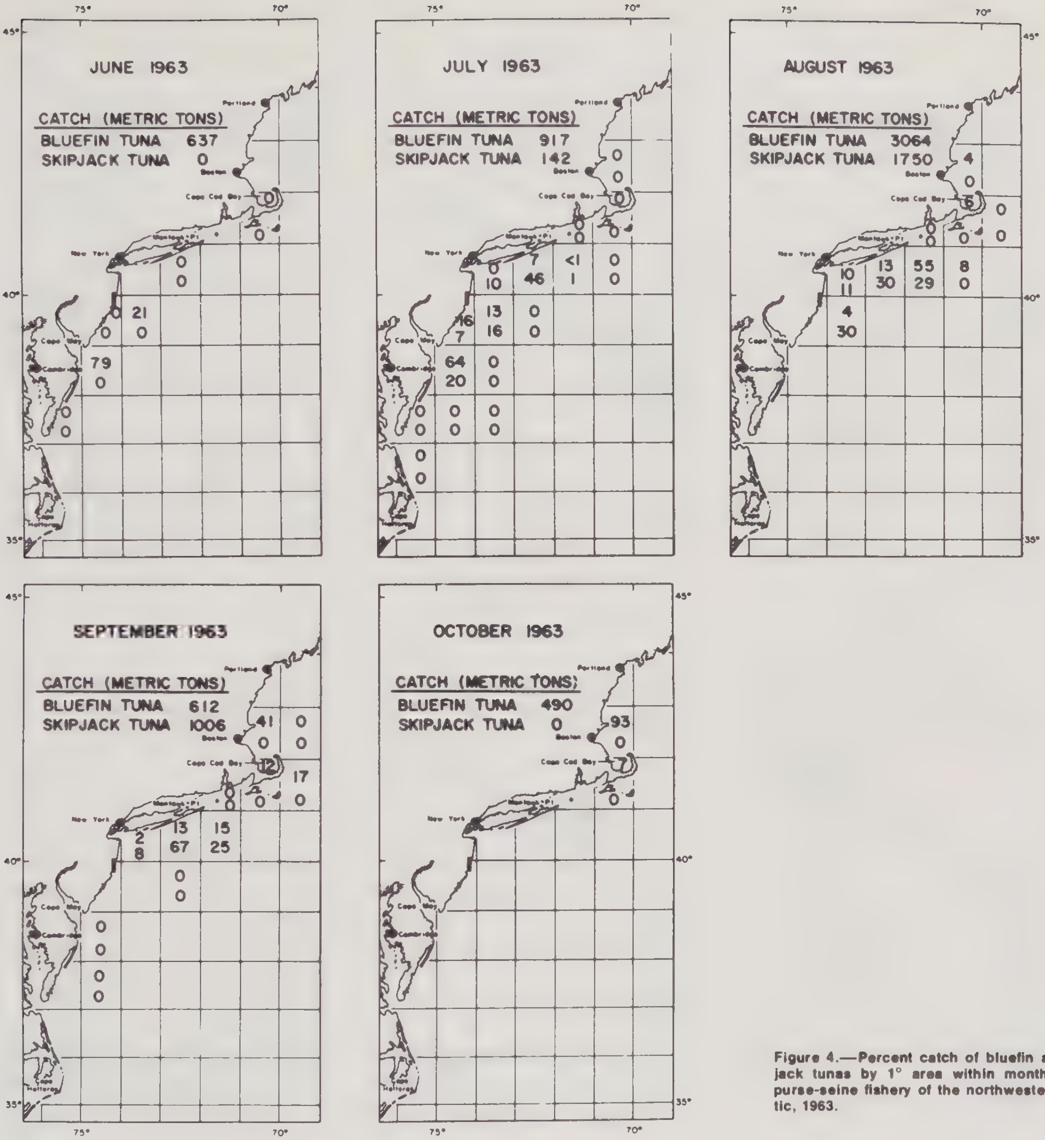
JUNE 1963
CATCH (METRIC TONS)
BLUEFIN TUNA 637
SKIPJACK TUNA 0
JULY 1963
CATCH (METRIC TONS)
BLUEFIN TUNA 917
SKIPJACK TUNA 142
AUGUST 1963
CATCH (METRIC TONS)
BLUEFIN TUNA 3064
SKIPJACK TUNA 1750
SEPTEMBER 1963
CATCH (METRIC TONS)
BLUEFIN TUNA 612
SKIPJACK TUNA 1006
OCTOBER 1963
CATCH (METRIC TONS)
BLUEFIN TUNA 490
SKIPJACK TUNA 0
Portland
Boston
Cape Cod Bay
Montauk Pt
New York
Cape May
Cambridge
Cape Hatteras
75°
70°
45°
40°
35°

Figure 4.—Percent catch of bluefin and skipjack tunas by 1° area within month for the purse-seine fishery of the northwestern Atlantic, 1963.

6,200 tons in 1963, decreased to 1,100 tons in 1968, increased again to 4,800 tons in 1970, and declined to 2,400 tons in 1972 (Fig. 1).

Since 1960, more than 90 percent of the total annual landings of bluefin tuna made by Canadian and U.S. fishermen has been attributed to the purse-seine fishery. The purse-seine catch of bluefin tuna was 140 tons in 1958; it peaked in 1963 at 5,770 tons, declined substantially in 1968, and rose to another peak of 4,290 tons in 1970 (Fig. 2). The catch then declined to about 1,780 tons in 1973.

Skipjack tuna and small amounts of yellowfin tuna are also caught in the bluefin tuna fishery. The catches of tropical tunas, however, are usually a minor part of the total catch, although in 1964 the skipjack tuna catch of 4,970 tons was nearly equal to the bluefin tuna catch of 5,170 tons (Table 1).

The fishery operates during a short season, June through early October, with virtually all (90 percent or more) of the catch and effort concentrated in July and August (Fig. 3). Weather is believed to be an important determining factor for the short season. Availability is another. Apparently, changes in migration patterns influence the availability of bluefin tuna to the purse-seine fishery (Mather, Rothschild, Paulik, and Lenarz[5]). Wilson (1965) stated that the purse-seine fishing season was increased by expansion of the fishery into southern fishing grounds, where schooled fish are available earlier in

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[5] Mather, F. J. III, B. J. Rothschild, G. J. Paulik, and W. H. Lenarz. Preliminary analysis of bluefin tagging data. Manuscript, 27 p. National Marine Fisheries Service, Southwest Fisheries Center, La Jolla, California 92037.

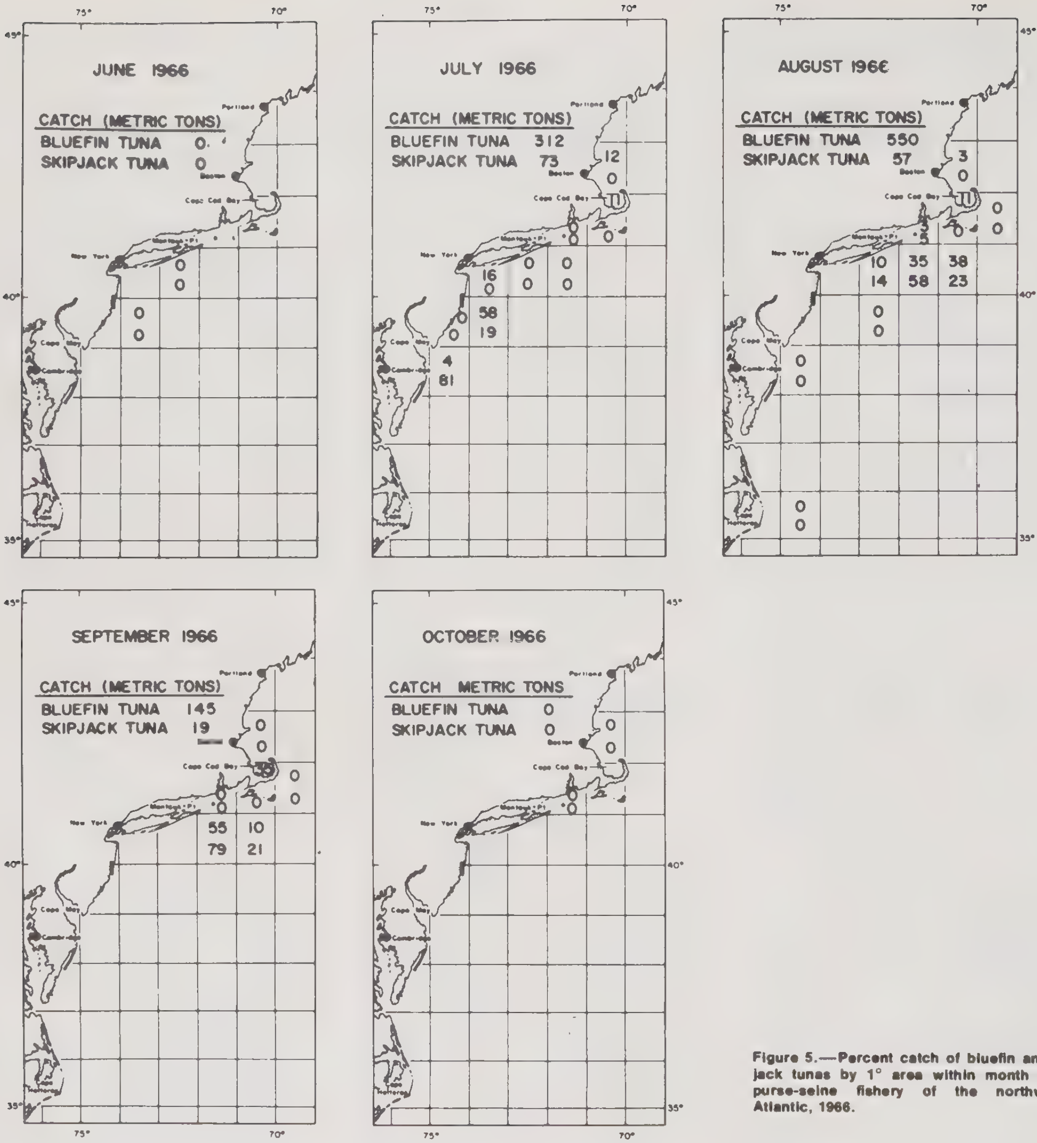
JUNE 1966
CATCH (METRIC TONS)
BLUEFIN TUNA 0
SKIPJACK TUNA 0
JULY 1966
CATCH (METRIC TONS)
BLUEFIN TUNA 312
SKIPJACK TUNA 73
AUGUST 1966
CATCH (METRIC TONS)
BLUEFIN TUNA 550
SKIPJACK TUNA 57
SEPTEMBER 1966
CATCH (METRIC TONS)
BLUEFIN TUNA 145
SKIPJACK TUNA 19
OCTOBER 1966
CATCH METRIC TONS
BLUEFIN TUNA 0
SKIPJACK TUNA 0
Portland
Boston
Cape Cod Bay
Montauk Pt.
New York
Cape May
Cambridge
Cape Hatteras
75°
70°
45°
40°
35°

Figure 5.—Percent catch of bluefin and skipjack tunas by 1° area within month for the purse-seine fishery of the northwestern Atlantic, 1966.

the year than in the region north of Cape Cod.

During the early years, the 1950's and early 1960's, of the purse-seine fishery, a greater amount of the season's catch was made in September and October. The fishery during the early years was centered in Cape Cod Bay with little effort expended south of Martha's Vineyard (Wilson, 1965). In 1962, the fishery expanded south of Martha's Vineyard. Currently most of the bluefin tuna are caught in July and August off New Jersey and New York, perhaps before they can travel northeastward to be available in more northern waters in September or October (Sakagawa and Coan, Footnote 4; Mather et al, Footnote 5). Most current catches in September and October are made in Cape Cod Bay and consist of fish primarily larger than about 122 cm long. Generally, Cape Cod Bay is considered a good fishing ground for large bluefin tuna (Wilson, 1965).

The fishery operates within a small geographic area and the catch is obtained from only a few "key" 1° × 1° areas, those in which 20 percent or more of the bluefin tuna are caught in any one month. The percent catches in 1° × 1° areas by months for 3 years, 1963, 1966, and 1973 which represent years of peak catch (1963), low catch (1966), and recent catch (1973), are shown in Figures 4, 5, and 6. In June, there is not much fishing and usually only one or two key areas off the New Jersey coast are fished by the purse-seine fleet. In July, schooled bluefin tuna are caught in several key areas off New Jersey and Long Island, N.Y. between lat. 38°N and 41°N. In August and September,

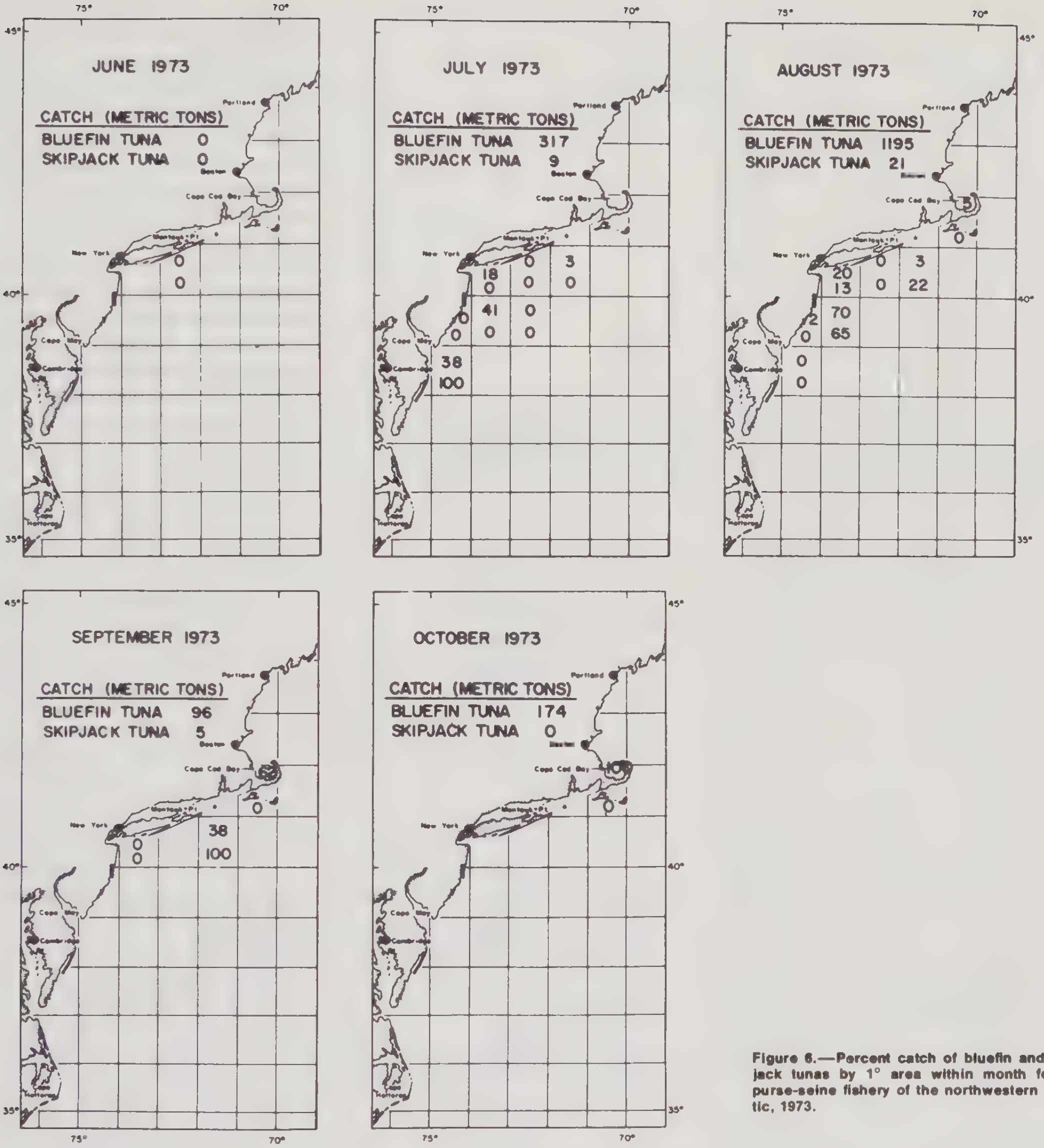
JUNE 1973
CATCH (METRIC TONS)
BLUEFIN TUNA 0
SKIPJACK TUNA 0
JULY 1973
CATCH (METRIC TONS)
BLUEFIN TUNA 317
SKIPJACK TUNA 9
AUGUST 1973
CATCH (METRIC TONS)
BLUEFIN TUNA 1195
SKIPJACK TUNA 21
SEPTEMBER 1973
CATCH (METRIC TONS)
BLUEFIN TUNA 96
SKIPJACK TUNA 5
OCTOBER 1973
CATCH (METRIC TONS)
BLUEFIN TUNA 174
SKIPJACK TUNA 0
Portland
Boston
Cape Cod Bay
Montauk Pt.
New York
Cape May
Cambridge
Cape Hatteras
75°
70°
45°
40°
35°

Figure 6.—Percent catch of bluefin and skipjack tunas by 1° area within month for the purse-seine fishery of the northwestern Atlantic, 1973.

the key areas are primarily off Long Island, although in 1963, substantial catches were made in a more northern area, off Boston, Mass. in September. Very little fishing is done in October because of poor weather conditions and availability. Catches during that month generally have been made off Rhode Island and Massachusetts and consist of larger fish (> 122 cm).

FISHING EFFORT

The number of vessels in the bluefin tuna purse-seine fishery increased from 1 boat in 1958 to 21 boats in 1964, and thereafter fluctuated between 4 and 13 boats, averaging about 9 boats fishing per year (Table 2).

Currently there are two major groups of seiners that participate in the fishery (Table 2). One group is seiners 92-181 tons capacity based primarily in New England ports which fish regularly for bluefin tuna in the northwestern Atlantic. Their trips seldom last more than a week. The second group is of seiners 364-1,000 tons capacity based in California, Puerto Rico, and New Brunswick, which fish irregularly in the northwestern Atlantic for tunas. Usually these large vessels enter the fishery only when tropical tuna fishing in the eastern Pacific or in the eastern Atlantic is poor. They are capable of remaining at sea for several months and usually return to their home ports to unload or for provisions.

Although there was a decrease of 14 boats (67 percent) in the fishery from 1964 to 1973, the carrying capacity of the fleet decreased only by 40 percent; the bluefin tuna catch decreased by 66 percent over the same period. The total carrying capacity of

Table 2.—Numbers and classes of purse seiners participating in the bluefin tuna fishery of the northwestern Atlantic Ocean, 1958-73.[1]

Year	Estimated total carrying capacity[2]	Class (carrying capacity[2]) 1 (0-45)	2 (46-91)	3 (92-181)	4 (182-272)	5 (273-363)	6 (364+)	Total
1958	40	1	-	-	-	-	-	1
1959	40	1	-	-	-	-	-	1
1960	40	1	-	-	-	-	-	1
1961	100	1	1	-	-	-	-	2
1962	1,000	1	2	2	1	1	-	7
1963	5,300	1	4	3	4	-	6	18
1964	8,100	1	4	3	2	2	9	21
1965	3,400	1	4	3	1	-	4	13
1966	900	1	2	3	-	-	1	7
1967	5,100	-	1	3	1	-	6	11
1968	700	-	1	3	1	-	-	5
1969	400	-	1	3	-	-	-	4
1970	3,500	-	1	3	-	-	4	8
1971	8,200	-	-	3	1	-	8	12
1972	6,200	-	-	3	1	-	7	11
1973	4,900	-	-	3	-	-	4	7

[1] Data are from the following sources: 1958-63 from Wilson (1965), 1964-73 from Mather F. J. III, Woods Hole Oceanographic Institution, Woods Hole, MA 02543 (pers. commun.) Beckett, J.S., Fisheries Research Board of Canada, St. Andrews, N.B. (pers. commun.) and the Inter-American Tropical Tuna Commission, La Jolla, CA 92037.

[2] Carrying capacity in metric tons.

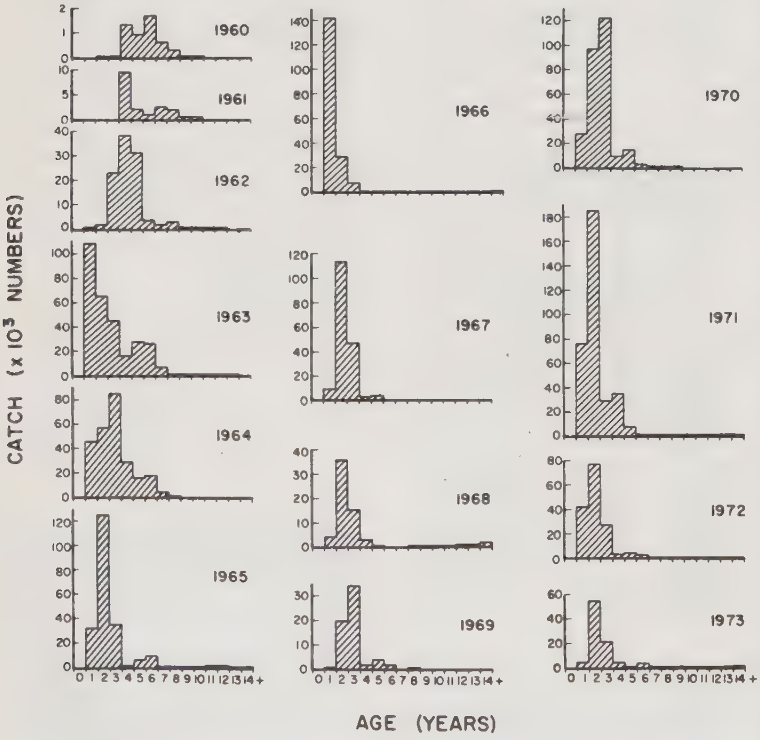

Figure 7.—Age composition of the purse-seine catch of bluefin tuna from the northwestern Atlantic.

the 1973 fleet was excessive in that it was about 4,900 tons, bringing in only 1,780 tons of bluefin tuna. It appears that the recent trend has been for larger but fewer boats in the fishery with a fleet carrying capacity in excess of the catch.

Data on nominal fishing effort in terms of fishing days have been collected from the bluefin tuna purse-seine fleet since the establishment of the fishery in 1958. It has been presented as effective effort (i.e. being proportional to instantaneous fishing mortality) in some published accounts (e.g. Aloncle, Hamre, Rodriguez-Roda, and Tiews, 1972; Lenarz, Jones, and Mather, 1972). Changes within the fishery, however, such as the entry of large seiners, the increased use of aircraft, and the southward expansion of the fishing grounds, have affected the fishing efficiency of the boats and the nature of the effort statistics collected through the years. For example, a unit of nominal fishing effort of a Class 3 seiner (92-181 tons) is not equal in terms of mortality generated to a unit of nominal fishing effort of a Class 6 seiner, (>364 tons), since Class 3 seiners more often use aircraft to aid in searching for schools and use smaller seines than do Class 6 seiners. Furthermore, Class 3 seiners were formerly in the unique position of being able to fish in both deep and shallow waters whereas larger seiners, with deeper nets, were able to fish only in deep water (Wilson, 1965). There has also been a change in the fishing effectiveness of perhaps all boats as the captains and crews became more proficient in the fishing techniques (Wilson, 1965), but particularly in that of Class 3 seiners as they increased their dependence on aircraft to locate schools and to assist in positioning the net. Because of these changes in the efficiency of the vessels, nominal fishing effort for the fleet is not a reliable measure of effective effort from one year to another.

AGE COMPOSITION OF CATCH

Sakagawa and Coan (Footnote 4) estimated the age composition of the purse-seine catch for 1960-72. I estimated the composition for the 1973 catch using that method. The results show three phases in the development of the purse-seine fishery (Fig. 7). The first was in 1960-62 when age groups

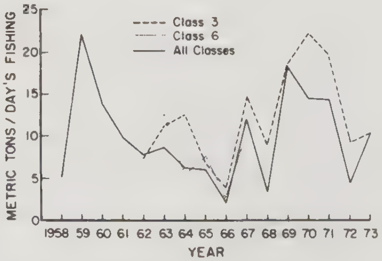

Figure 8.—Nominal catch rates by class of vessel in the purse-seine fishery for bluefin tuna in the northwestern Atlantic.

3-6 years dominated the catch. A transition phase followed in 1963 and 1964 when the catch was dominated by a combination of younger fish as well as 3-year old to 6-year old fish. The last phase began in 1965 when the young age groups (1-3 years) dominated the catch with few older fish represented. In 1973 the average length of bluefin tuna in the catch was 89 cm, whereas it was 140 cm in 1960.

The changes in the age composition of the catch should be recognized as influenced in part by the southward expansion of the fishing grounds. In the early stages of the fishery's development, the fishery was centered north of Cape Cod, where primarily large fish are available (Wilson, 1965). As the fishery expanded southward, beginning in 1962, into areas where younger fish are more available, more smaller fish were caught (Sakagawa and Coan, Footnote 4; Mather et al, Footnote 5). Finally, in the last phase the fishery was centered off New Jersey-New York, where primarily young bluefin tuna are found.

CATCH RATE

Most published catch rates (CPUE) for the northwestern Atlantic purse-seine fishery for bluefin tuna are based on total days fishing or total nominal effort (Fig. 8). As was stated above, nominal effort is not a reliable measure of effective effort, hence fishing mortality, because of changes, particularly in efficiency, of the vessels over the years. Consequently, the nominal CPUE's in Figure 8 are likewise unreliable for indexing abundance unless change in vessel efficiency is taken into account.

Sakagawa and Coan (Footnote 4) indicated that vessel efficiency, at least for Class 3 vessels, probably has increased since the mid-1960's when vessels began relying more heavily on aircraft to locate schools and cooperating more fully among themselves in fishing operations. In Figure 8, the nominal CPUE's for Class 3 vessels since the mid-1960's are therefore probably overestimated and should be adjusted downward to reflect the increase in vessel efficiency. The CPUE's for the 1970's would then indicate a more pronounced decline than depicted in Figure 8.

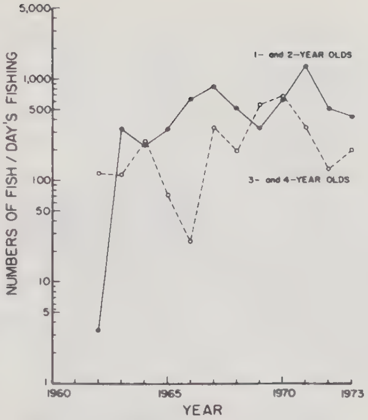

Figure 9.—Nominal catch rates of 1- and 2-year old and 3- and 4-year old bluefin tuna for Class 3 vessels in the purse-seine fishery for bluefin tuna in the northwestern Atlantic.

The CPUE's for Class 3 vessels in terms of numbers of fish are shown in Figure 9. Only CPUE's for age groups 1 and 2 and 3 and 4 are shown. These age groups represent sizes of fish (< 140 cm) that are most sought after by the purse-seine fishermen. The CPUE's have not been adjusted for changes in vessel efficiency. They nevertheless indicate that apparent abundance of age groups 1-4 was at a high level and the CPUE of 3- and 4-year olds was less than that of the recruits, 1- and 2-year-old fish, in most years.

In the 1970's, the general trend of CPUE's for both the recruits and 3- and 4-year olds is downward, although the CPUE of recruits somewhat leveled off and that of 3- and 4-year olds increased in 1973. This declining trend is probably associated with changes in survival and availability of recruits and changes in the abundance of the spawning stock.

DISCUSSION

The bluefin tuna catch of the purse-seine fishery of the northwestern Atlantic ranged from 138 tons in 1958, the year the fishery was established, to 5,770 tons in 1964. The most recent catch was 1,781 tons. The fluctuations in catch are possibly due to (1) variation in migration patterns (Mather et al, Footnote 5) and location of the fishery, (2) variation in the amount of effective effort used to bring the catch, (3) variation in recruitment or stock abundance, and (4) variation in fishing effort of the sport fishery, which competes with the seine fishery for bluefin tuna, or a combination of any of these.

Besides the purse-seine and sport fisheries of the northwestern Atlantic, commercial fisheries in the Bay of Biscay, off Portugal, and off northern Africa also catch small Atlantic bluefin tuna (50-122 cm long) during the summer and fall. There is uncertainty as to whether these widely separated fisheries normally exploit fish from separate stocks or from a common stock. Tagging experiments, however, have demonstrated that, at least in some years, fish of similar stocks are exploited in the eastern and western Atlantic (FAO, 1972). Mather, Bartlett, and Beckett (1967), for example, examined tagging data and hypothesized that between the summers of 1965 and 1966 there was sufficient migration of young bluefin tuna from west to east to cause a decline in catch from the northwestern Atlantic and a concomitant increase in catch from the Bay of Biscay. Aloncle[6] concluded from tag returns of small bluefin tuna tagged in the eastern Atlantic that independent American and European stocks exist but that east-west migration does occur. Thus, the degree of transatlantic migration has at least in some years affected the catch from the northwestern Atlantic.

Tagging studies have also demonstrated that in the northwestern Atlantic changes in migration pattern with age of fish affect the availability of different age groups of bluefin tuna to the purse-seine fishery (Mather et al., Footnote 5). Mather et al., (Footnote 5) found that a higher proportion of tagged 1.4-year old bluefin tuna returned to the fishing area off the United States east coast the year after their release than did older fish. Since the age groups represented in the purse-seine catch have varied, availability of the different age groups has probably contributed to the variation in the catch. Of course, superimposed on this effect of variable availability is the effect of variable year-class strength, which would also contribute to variation in catch.

[6] Aloncle, H. Marquage de thons rouges dans le Golfe de Gascogne. Manuscript, 11 p. Institut des Pêches Maritimes, La Noë-Route de la Janelière, 44-Nantes.

Brailing bluefin tuna from a purse seine net off the U.S. east coast.

Trends in the nominal fishing effort for the purse-seine fishery suggests that total effective effort has fluctuated owing to changes in the number, size, and efficiency of vessels in the fleet. The fluctuation, of course, contributed to the variation in the purse-seine catch.

Class 3 nominal catch rates for the 1970's are overestimated relative to those of earlier years because of improved fishing efficiency since the mid-1960's. When improved efficiency is taken into account, a declining trend prevails in the catch rates for the 1970's; the current catch rate is low, perhaps at the lowest level since the establishment of the fishery. Thus, the catch rates of the 1970's suggest that the stocks fished by the fishery possibly declined in abundance or availability, which has contributed to the recent decline in the purse-seine catch.

Finally, sport fishermen in the northwestern Atlantic compete with seine fishermen for bluefin tuna. Although the total sport catch of schooled bluefin tuna is not known, rough estimates (Sakagawa and Coan, Footnote 4) suggest that the catch was large enough in some years to have an impact on the purse-seine catch.

ACKNOWLEDGMENTS

I wish to thank the following individuals for providing information used in this report: F. J. Mather III and J. M. Mason, Jr. of the Woods Hole Oceanographic Institution; J. S. Beckett of the Canadian Fisheries and Marine Service; and B. G. Thompson of the National Marine Fisheries Service. The generous cooperation of the captains and owners of American tuna vessels that fish in the northwestern Atlantic and tuna canneries on the east coast of the United States and in Puerto Rico is acknowledged. The Inter-American Tropical Tuna Commission and the Woods Hole Oceanographic Institution collected part of the data used in this report under National Marine Fisheries Service contracts.

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CHLORINATED HYDROCARBONS IN SEAWATER: ANALYTICAL METHOD AND LEVELS IN THE NORTHEASTERN PACIFIC

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ABSTRACT

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A method is described for analyzing nanogram quantities of chlorinated hydrocarbons from 1-l samples of seawater. Seawater samples are pumped through a copper column containing a mixture by weight of 5% activated carbon powder, 10% MgO and 85% refined diatomaceous earth. The chlorinated hydrocarbons in the seawater are adsorbed or trapped on the column and subsequently eluted with 30% benzene in acetone (v/v) for analysis by gas-liquid chromatography.

This procedure was used to analyze chlorinated hydrocarbon levels in samples collected off the southern California coast. We suggest that anthropogenic chlorinated hydrocarbons can be used for the investigation of large-scale ocean currents and mixing processes.

INTRODUCTION

The objective of this work was to develop a method for analyzing small-volume samples of seawater (i.e., 1 liter) for low levels of chlorinated hydrocarbons (CHC). Although the sensitivity of modern electron-capture detectors approaches 10^{-12} g of chlorinated hydrocarbon, a more practical working limit is 10^{-10} g. This allows the detection of 0.1 parts per trillion (pptr) from a 1-l sample of water. In practice, contamination from reagents and containing vessels is a more stringent restriction on sensitivity than is the detection limit of the electron-capture detector. We have found that solvent extraction (using polar and non-polar solvents).becomes less than 100% efficient when the ratio of sample volume to solvent volume exceeds about 15:1. The procedure described here was designed to minimize manipulative steps and to reduce contamination introduced through reagents by allowing a sample volume to reagent volume ratio of at least 63:1 (with 0.5 g of adsorbent, 15.5 ml of solvent and a 1-l sample).

It is reasonable to expect some portion of the chlorinated hydrocarbons present in seawater to be adsorbed on colloidal particles (Pfister et al., 1969). Fox et al. (1952) have demonstrated the retention of colloidal micelles by adsorptive filters composed of MgO and refined diatomaceous earth. Presumably, CHC associated with colloids will be trapped by a column containing a bed of polar adsorbents. The presence of a non-polar adsorbent (i.e., activated carbon) in the filter bed will scavenge CHC from the dissolved state in water (Burchfield and Johnson, 1965). Chlorinated hydrocarbons trapped in the interior of a micelle of surface active material suspended in seawater can be recovered in a mixed bed of polar and non-polar adsorbents if the micelle is disrupted by viscous shear forces, so that the CHC can adsorb onto the non-polar surfaces or if the micelle is adsorbed without disruption in the filter bed.

A column packed with fine-grained adsorbents has many advantages. Among these are:

(1) chlorinated hydrocarbons desorbing from the surface of a colloid must be transported to the non-polar adsorbent surface by molecular and turbulent diffusion. Small distances between particles in the adsorbent bed mean smaller distances and times over which these diffusive processes must operate.

(2) Viscous shear forces are greater in a column containing an adsorbent with small particle diameter.

(3) Since finer-grained adsorbents have a higher specific surface, smaller columns can be used which reduces the amount of solvent necessary for elution of the adsorbed material.

(4) Tailing during elution is also minimized because finer-grained particles of carbon have less extensive pores within each adsorbent particle.

These considerations guided our choice of a small column with a mixed bed or polar and non-polar adsorbents having high specific surface area and small particle diameter.

In the work reported here we have tested the efficiency and reproducibility of a column-scavenging method for analyzing chlorinated hydrocarbons in 1-l samples of seawater and we report levels found in samples taken off the southern California coast.

METHODS AND MATERIALS

Seawater samples are pumped through a column containing a mixture by weight of 5% activated carbon powder (Matheson, Coleman and Bell), 10% MgO powder (Mallinckrodt), and 85% refined diatomaceous earth (Celite$^{t.m.}$, Johns-Mansville). The chlorinated hydrocarbons in the seawater are adsorbed or trapped on the column and subsequently eluted with a 30% benzene in acetone (v/v — all solvents Mallinckrodt "nanograde" redistilled in glass). Batches of the adsorbent are cleaned in a 29 x 2.2 cm I.D. glass column by eluting with a combination of strongly polar and non-polar solvents. We have found that elution with a combination of water—acetone, acetone—benzene, and finally with benzene is most effective in removing interfering CHC from the adsorbent. The clean adsorbent is dried in a rotary evaporator and stored in a sealed container.

The scavenging columns are made of copper tubing (100 x 5 mm I.D.) with a short length of smaller copper tubing (2 mm I.D., 3.5 mm O.D.) soldered to one end to serve as a tip. The tip is plugged with glass wool before adding the adsorbent. Organic solvents are pumped through the column with compressed air by attaching a glass pipette containing the solvent to the column with a short piece of PTFE tubing (5 mm I.D., 1 mm wall thickness). The mouthpiece of the pipette is connected to the compressed air source with a piece of pliable tubing. The water sample is pumped through the column by a high-pressure chemical feed pump (Precision Control Products Corporation, Model #16501-11). The piston and valves are made of stainless steel and PTFE. Swagelock fittings are used to connect the pump, tubing and column.

Procedure

The column is packed with 0.5 g of clean, dry adsorbent by gentle tapping. The packed column is rinsed by passing through the column 10 ml of benzene, followed by 20 ml of 30% benzene in acetone. The last 5 ml of the 30% benzene in acetone is collected to serve as a reagent blank. The blank is concentrated under vacuum at room temperature and an appropriate amount is analyzed by gas-liquid chromatography (GLC). If necessary, the column is rinsed again until a suitable blank is obtained. Before each use, the column is rinsed with 5 ml of acetone and dried with compressed air (check the air for CHC contamination). It is not essential to dry the column completely. A 1-l sample of seawater is pumped through the column at the rate of 10 ml/min. Excess water is forced off the column with compressed air before the chlorinated hydrocarbons are eluted with 10—15 ml of 30% benzene in acetone. The solvent is separated from the water fraction of the eluate and saved. The remaining eluate water (<0.5 ml) is extracted with 0.5 ml n-hexane which is pooled with the solvent fraction. The solvent—CHC residue fraction is concentrated under vacuum at room temperature and cleaned-up on alumina (McClure, 1972) prior to analysis by GLC. Typically, after alumina clean-up, the CHC residue from a 1-l sample of seawater containing between $1\text{—}10 \cdot 10^{-9}$ CHC/l is evaporated just to dryness, reconstituted in 100 μl of iso-octane from which 20 μl is analyzed by GLC. Generally, pesticide residues are also separated from polychlorinated biphenyls (PCB) on silica-gel prior to analysis (McClure, 1972).

Chlorinated hydrocarbons were analyzed on a Hewlett-Packard Model 5700 gas-liquid chromatograph with a ^{63}Ni electron-capture detector. The glass column (2 mm x 6 ft) was packed with 1.5% SP2250, 1.95% SP2401 on 100/120 Supelcon AW-DMCS. Injection port, oven, and detector temperatures were 250°C, 200°C, and 300°C, respectively. The chlorinated hydrocarbons detected in seawater samples were identified by comparison with known standards, the retention times using gas-liquid chromatography and R_f values from liquid—solid column chromatography on silica-gel (McClure, 1972). Pesticide standards were supplied by the Environmental Protection Agency, Perrine Primate Laboratory, Florida, U.S.A. PCB standards were supplied by the Monsanto Company, St. Louis, Missouri, U.S.A. The predominant PCB found in the seawater samples was Aroclor 1254 (trade mark of the Monsanto Company; the last two digits specify weight percent chlorine). Unless indicated otherwise, "PCB" will refer to the 54% chlorine mixture in the following text.

Introduction and analysis of ^{14}C-DDT in seawater

^{14}C-DDT was added to seawater so that we could test the efficiency of the adsorbent in removing CHC from seawater and the recovery of CHC from the column during elution. ^{14}C-DDT was introduced into seawater either in the vapor state and/or associated with airborne particles smaller than 0.45 μm. $5 \cdot 10^{-5}$ g ^{14}C-DDT dissolved in 200 μl of n-hexane was pipetted onto a glass wool plug stuffed into a short section of glass tubing (4 mm I.D). After allowing the n-hexane to evaporate, the upstream end of the tubing was connected to a membrane filter (pore size, 0.45 μm). Downstream, the tubing was connected to another membrane filter (pore size, 0.45 μm) and then to the inlet port (glass tubing, 6 mm O.D.) of a 20-l glass carboy filled with membrane-filtered seawater (pore size, 0.45 μm). The carboy was sealed with a cork stopper. The inlet tube extended to the bottom of the carboy and was fitted at the end with an airstone. The glass exit tubing originated from above the water level in the carboy. Between the carboy exit port and a vacuum source was connected an 8-mm diameter by 50-mm long air-trap tube filled with glass wool impregnated with mineral oil in series ahead of an impinger (to catch excess oil blown off the glass wool). By applying a vacuum to this system, laboratory air was drawn through the filter, over the solid ^{14}C-DDT and bubbled through the seawater. Presumably, the majority of the ^{14}C-DDT leaving the glass wool was in the vapor state. However, the possibility exists that some of the ^{14}C-DDT became associated with sub 0.45 μm airborne particles or that solid particles of ^{14}C-DDT (<0.45 μm) passed through the system. As the ^{14}C-DDT passed through the seawater some of it remained, either in the dissolved state (Bowman et al., 1960) or associated with particles. Any ^{14}C-DDT that did not remain in the seawater was collected by the air trap as it left the system. The seawater was monitored as the ^{14}C-DDT was introduced until the desired concentration was achieved.

Seawater samples containing ^{14}C-DDT were analyzed using the procedure described in this report except that the ^{14}C-DDT residues were measured with a Beckman LS-100C Liquid Scintillation Counter. The results were verified by solvent extraction of replicate seawater samples using mixed polar and non-polar solvents. A 1-l sample of seawater was extracted twice with a mixture of 40 ml of hexane and 20 ml of acetone. The pooled solvent extracts were concentrated on a rotary evaporator, dried with Na_2SO_4, evaporated just to dryness under vacuum at room temperature and transferred into scintillation fluid with 2 × 100 μl aliquots of iso-octane. The CHC contamination inevitably introduced from such a large volume of solvent did not interfere with measurements based upon ^{14}C activity.

RESULTS AND DISCUSSION

To test the efficiency of the scavenging column it was necessary to prepare quantities of seawater containing known amounts of radiocarbon-labeled chlorinated hydrocarbons which were dispersed in the water in states of aggregation approximating those in ambient nearshore oceanic conditions. Although it is likely that slightly soluble (~ 1 part in 10^9) organics associate with natural surface-active materials in the sea, it was not thought proper to introduce additional surface-active solvents (such as methanol or acetone) as is the usual practice for dispersing slightly soluble pollutants. The method described above for introduction of ^{14}C-DDT as an aerosol or vapor was therefore employed and resulted in solutions (or dispersions) which remained stable for periods of at least eighteen days in sealed carboys.

Procedure evaluation

Ten 1.0-l replicate samples of seawater containing ^{14}C-DDT were analyzed to evaluate the procedure presented here. We tested the efficiency of the adsorbent in removing DDT from the seawater, the recovery of the DDT from the adsorbent by elution, and the reproducibility of the procedure. The analyzed samples were subsequently extracted with mixed polar and non-polar solvents to recover any of the ^{14}C-DDT not adsorbed onto the column. At a flow rate of 10 ml/min, 99.3% of the ^{14}C-DDT was removed from the seawater by the column. Ten ml of 30% benzene in acetone eluted 97.7% of the ^{14}C-DDT from the column. A total of 15 ml was required for 100% recovery. The average ^{14}C-DDT concentration was $13.4 \cdot 10^{-9}$ g l^{-1} (13.4 pptr) with a standard error of ±0.3 pptr. Additional samples were solvent-extracted to confirm these results.

PCB recovery from the adsorbent bed

Recovery of PCB from the adsorbent bed was tested by wetting the column with 10 ml of seawater, spiking the column with 20 μl of iso-octane containing $2 \cdot 10^{-8}$ g of Aroclor 1254 (Monsanto), followed by another 10 ml of seawater before elution with 30% benzene in acetone. In five repetitions of this test, recovery was always complete. This test also demonstrates that the column is not overloaded by 20 μl of a non-polar material. Total dissolved organic matter in seawater is frequently about 10 mg l^{-1} (Fox et al., 1952). In one liter, the volume of organic matter having a density of 0.5, present at 10 mg l^{-1} would be 20 μl. Since some fraction of the total organic matter in seawater is polar and is therefore not in direct competition with non-polar CHC for adsorption sites on the column, the column-loading achieved in this test is equivalent to the passage through the column of a 1-l sample of seawater containing somewhat more than 10 mg l^{-1} of dissolved organic matter.

Replicate samples of La Jolla seawater

Seven 1.0-l replicate samples from the seawater system at the Southwest Fisheries Center, La Jolla, California, were analyzed for chlorinated hydrocarbons. The average concentration of Aroclor 1254 was $2.9 \cdot 10^{-9}$ g l^{-1}. The range was 2.5—$3.3 \cdot 10^{-9}$ g l^{-1}. Standard error was $\pm 0.3 \cdot 10^{-9}$ g l^{-1}. DDT and DDE levels for these replicate samples were less than $0.1 \cdot 10^{-9}$ g l^{-1}.

Seawater samples from the Gulf of Santa Catalina

Table I lists values and Fig.1 shows locations of CHC measurements made April 8—12, 1974, in the Gulf of Santa Catalina, south of Los Angeles. Analyses were performed aboard the R/V "David Starr Jordan", within 4 h of sampling. Samples were taken with 2-l sampling bottles machined from hard, unplasticized Lexan with ball-valve seats of PTFE. No plasticized elastomers or lubricants were employed. The bottles were checked for contamination by rinsing them with equal parts n-hexane and acetone, concentrating the rinse and analyzing the concentrate. Pre-extracted seawater was also stored overnight in a Lexan bottle and reanalyzed in order to assess contamination from the entire sample-taking and analysis procedure. Blanks ranged from below the detection limit to 1 pptr for PCB and to 0.1 pptr for DDT. (We discovered that the blanks were negligible when the efflux from the first extraction was collected in a covered vessel. Aerosol deposition of PCB in southern California is commonly in the range 10^{-6}—10^{-7} g m^{-2} day^{-1} (McClure and La Grange, MS) and this flux was shown to contribute $\sim 10^{-9}$ g to the uncovered 1-l efflux-collecting vessel during the 100 min required to do the initial extraction. This contamination influenced only the blanks since the samples were always kept covered.)

Bucket samples were taken while under way from the weather bow of the ship and the surface Lexan bottle samples were taken at 1 m depth after first lowering to 50 m to rinse the bottle.

The most prominent CHC detected in the seawater samples most closely matched the Aroclor 1254 standard (Fig.2). Various other GHCs were present including additional PCB homologues, pp′-DDE and pp′-DDT.

The CHC concentrations detected by us in the Gulf of Santa Catalina are comparable to the levels measured by Pavlou et al. (1974) off the southern California coast using polyurethane foam to scavenge CHCs from the seawater.

TABLE I

Chlorinated hydrocarbon concentrations in seawater at various depths off southern California in pptr (10^{-9} g l^{-1})

Station position	Sampling method	Depth (m)	PCB (1254 Aroclor)	p,p′-DDE	p,p′-DDT	Date
San Diego Bay	bucket	surface	9.5	0.4	0.2	4/8/74
1 C 33°18.8′N 118°36.6′W	bucket	surface	3.0	<0.1	0.3	4/8/74
L I 33°10.5′N	Lexan	surface	7.5	<0.1	0.4	4/9/74
118°27.5′W	Lexan	500	7.2	1.1	0.1	4/9/74
L II 33°24.9′N	Lexan	surface	9.6	1.0	0.1	4/9/74
118°49.6′W	Lexan	500	7.7	0.9	0.7	4/9/74
”	Lexan	1,000	10.3	0.3	0.5	4/9/74
San Pedro Harbor	bucket	surface	35.6	4.6	1.9	4/9/74
San Onofre	bucket	surface	14.0	0.8	0.3	4/9/74
L III 33°12.5′N	Lexan	surface	9.4	0.2	<0.1	4/9/74
117°44.0′W	Lexan	500	6.1	0.5	0.2	4/9/74
”	Lexan	800	4.2	1.2	0.6	4/9/74
L IV 32°31.0′N	Lexan	500	2.9	0.3	N/D	4/11/74
118°03.0′W	Lexan	1,500	2.3	0.3	N/D	4/11/74

In that study, inshore surface samples contained an average of $5.4 \cdot 10^{-9}$ g l^{-1} ΣPCB and $0.9 \cdot 10^{-9}$ g l^{-1} ΣDDT. Offshore samples contained an average of $3.6 \cdot 10^{-9}$ g l^{-1} ΣPCB and $0.5 \cdot 10^{-9}$ g l^{-1} ΣDDT. Slightly lower concentrations of CHCs were detected by Bidleman and Olney (1974) in the Sargasso Sea using a dichloromethane extraction method (average level in subsurface water, $1.1 \cdot 10^{-9}$ g l^{-1} PCB). Harvey et al. (1973) detected higher levels in the North Atlantic (average, $35 \cdot 10^{-9}$ g l^{-1} PCB) using Amberlite XAD-2 resin to extract CHCs from the seawater.

Profiles of salinity and temperature were taken at each station where Lexan-bottle casts were made and the depth of the mixed layer (pycnocline or main thermocline) was found to be less than 200 m in every case. The fact that the

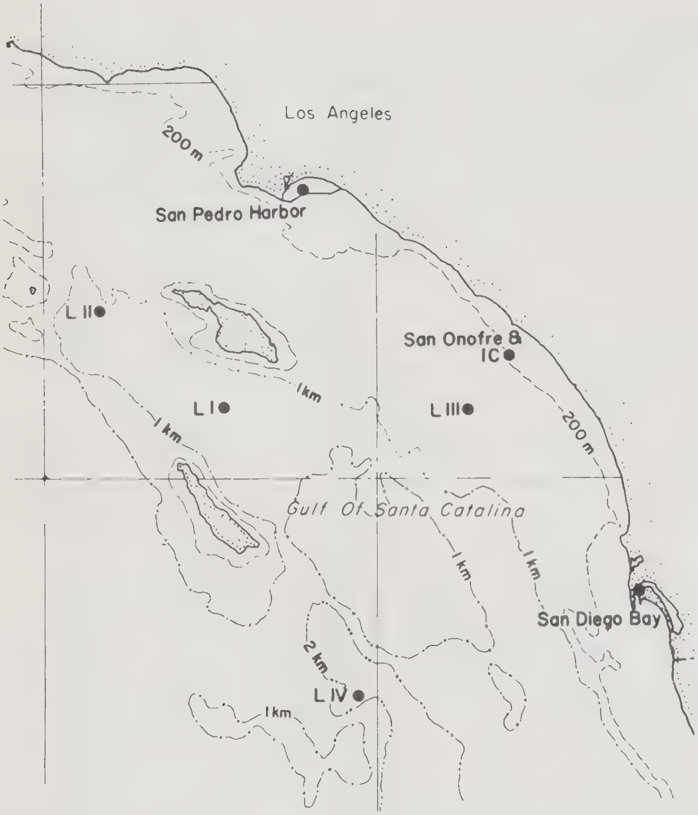
Los Angeles
200 m
San Pedro Harbor
L II
San Onofre &
IC
1 km
L I
L III
200 m
1 km
Gulf Of Santa Catalina
1 km
1 km
San Diego Bay
2 km
L IV
1 km

Fig.1. Sampling stations and bathymetry off southern California.

CHCs are not confined to the mixed layer and at some stations were as abundant below as in the mixed layer indicates that sedimentary processes are at least as important as advection in the dispersal of lipophylic materials in the ocean. Harvey et al. (1973) reported a decrease in PCB concentration with depth in the North Atlantic, but those stations were taken at a greater distance off shore. It is likely that the dispersal of CHC downward through the water column is associated with sedimentary processes which decrease with distance from the shore.

CONCLUSION

The procedure described in this paper is a convenient and reliable method for the determination of nanogram quantities of CHC from 1-l samples of seawater. Procedure blanks are easy to run and the location of sources of contamination is simplified since the number of solvents, reagents, articles of glassware and manipulative steps in the procedure have been held to a minimum.

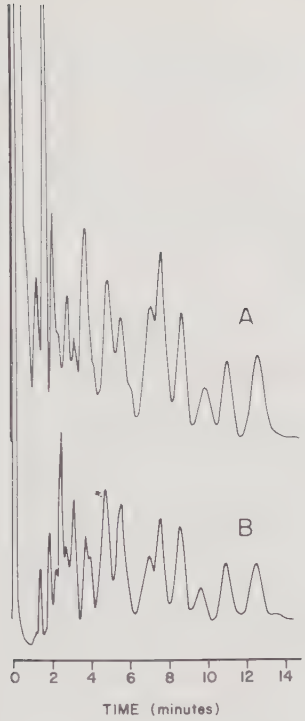

Fig.2. Gas chromatogram of CHCs from a surface sample taken in the northeastern Pacific (A) and an Aroclor 1242—1254 standard (B).

The highly chlorinated polychlorinated biphenyls are among the most refractory of synthetic organic chemicals to both chemical and biological degradation. Samples of water from the eastern Pacific all yield gas chromatograms (after preliminary liquid chromatographic separation of pesticides — McClure, 1972) which are nearly identical to the Aroclor 1254 mixture with regard to ratios of isomers present. This is strong evidence for the anthropogenic nature of PCBs in the ocean. To be consistent with these measurements, any degradation must take place in such a way that all isomers present in the Aroclor 1254 mixture be degraded at very nearly the same rate or the degradation rate must be slow compared to the characteristic times for dispersal or sedimentation from the water.

The strengths and distribution of sources of PCB to the ocean are amenable to measurement and the resulting distribution of pollutants in the sea will provide useful information about the horizontal and vertical transport of the whole class of low-vapor-pressure, non-polar nutrients as well as pollutants.

ACKNOWLEDGMENTS

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DEDICATIONS

John K. Howard

1891-1965

John K. Howard was an outstanding example of a man whose interest in ocean science led to a second career after retirement from law practice. His many friends throughout the world remember his great enthusiasm, combining a passion for sport fishing with a desire to increase our knowledge of the big-game fishes, in particular the billfishes. He sponsored and directed a research program at the Institute of Marine Science, University of Miami, and also gave much logistic aid to ichthyologists around the world. His travels took him to East Africa, Australia, New Zealand, and Japan. He also visited Portugal, Spain, and Italy, where he collected large numbers of spearfish and white marlin in an attempt to solve the specific identity of the Mediterranean spearfish.

Shortly before his death he completed, with Dr. Shoji Ueyanagi of Japan, a large report on the seasonal and geographic distribution of billfishes in the Pacific Ocean. His similar work on these fishes in the Indian Ocean was completed by Dr. Walter A. Starck II.

John K. Howard was born in Paris, France, on 4 April 1891. He received his undergraduate degree from Harvard College in 1915 and his law degree from Harvard College in 1917. After retiring from law practice he studied ichthyology at the University of Miami. He served in both World Wars as an army officer, achieving the rank of colonel.

Oscar Elton Sette

1900-1972

Dr. Sette's contributions to fisheries science are manifold and cover more than half a century of active work as a fishery biologist and administrator.

From 1949 to 1955 he acted as chief of the newly established Pacific Oceanic Fishery Investigations (POFI), a Honolulu-based research facility of the Fish and Wildlife Service, U.S. Department of the Interior (presently the Honolulu Laboratory of the Southwest Fisheries Center, National Marine Fisheries Service, NOAA, U.S. Department of Commerce). Here he was responsible for the development of a high-seas fisheries program in the central Pacific Ocean, a program that laid the groundwork for much of what is known today of the tunas, sharks, and billfishes of this expansive body of water. Although much of the research effort of his staff at POFI was devoted to tunas as the principal pelagic species of commercial interest, Dr. Sette was among the first to recognize the need to study the full spectrum of the food web in order to understand the various biological resources of the ocean. The research on billfishes undertaken during and after his tenure in Honolulu is a result of his appreciation of the need to collect data from all levels of the ecosystem. Dr. Sette was also one of the first to advocate integrating the field of biology with those of oceanography and meteorology.

Oscar Elton Sette was born in Clyman, Wis., on 29 March 1900. In 1910 his family moved to southern California, where he completed his intermediate and high school education. He received his Bachelor of Arts degree from Stanford University in 1922, a Master's degree in Biology from Harvard University in 1930, and a Doctorate in Biology from Stanford University in 1957.

During a career which extended over 50 years, Dr. Sette served in various research and administrative capacities with the California State Fisheries Laboratory, and the National Marine Fisheries Service and its predecessor agencies. Beginning in 1924 with the U.S. Bureau of Fisheries, he held positions as Chief, Division of Fishery Industries in Washington, D.C.; Chief of the North Atlantic Fishery Investigations; Chief of the South Pacific Fishery Investigations; Chief, Pacific Oceanic Fishery Investigations; and Director, Ocean Research Laboratory, on the campus of Stanford University.

De. Sette "retired" in 1970, but continued his research as an "annuitant" employee of the Federal Government until his death in July 1972.

GENERAL REPORT

Introduction

The Symposium was sponsored by the National Marine Fisheries Service (NMFS) of the National Oceanic and Atmospheric Administration, U.S. Department of Commerce, and was held at Kailua-Kona, Hawaii, from 9 to 12 August 1972. The Symposium was cosponsored by the County of Hawaii, the Hawaii State Division of Fish and Game, the Marine Affairs Coordinator of the State of Hawaii, and the Hawaiian International Billfish Tournament (HIBT). The Food and Agriculture Organization of the United Nations (FAO) also actively supported the Symposium.

Background

Since the mid-1960's the pelagic waters of the world's oceans extending from about lat. 40°N to 40°S have been fished with longline gear for fish species of commercial importance. The principal species sought have been the tunas; thus, these pelagic fishes have received considerable attention from biologists and fishery administrators. Tunas have been the subject of discussions at the Scientific Meeting on the Biology of Tunas and Related Species held in La Jolla, Calif., 2-14 July 1962; the Symposium on Scombroid Fishes held in Mandapam Camp, India, 12-15 January 1962; and the Governor's Conference on Central Pacific Fishery Resources held in Hawaii, 28 February-12 March 1966. Further, those tuna species of commercial importance have been the focus of attention in recent years and have been the subject of review at annual international meetings, e.g., Inter-American Tropical Tuna Commission (IATTC) and International Commission for the Conservation of Atlantic Tunas (ICCAT), and domestic meetings, e.g., Pacific Tuna Conferences.

Unlike the tunas, the other major group of pelagic fishes taken by longline gear—the billfishes—has received very little attention. The relatively large size attained and the difficulty in obtaining adequate numbers of specimens for examination have kept our knowledge of billfishes to a low level. Studies undertaken by individual scientists have been based on few specimens, specimens principally collected at the centers of sport fisheries. Access to data and specimens collected by the extensive longline fisheries has been limited primarily because the accommodations aboard commercial longline vessels are limited and fishing trips generally extend over periods of several months. The principal reason for this restricted information, however, has been the lack of urgency and priority expressed by administrators of the major fishing countries.

During the past 5 or 6 yr the need to assess the status of stocks of the various species of the billfishes has become apparent. This has been reflected in the concern expressed by sport fishermen throughout the world regarding the declining catches of billfishes and the increased importance of billfishes noted by the commercial interests. The sport fishery catch rates of sailfish in the Pacific waters off Mexico have declined dramatically in the last decade. This decline has been attributed to the intensive longline fishery which started in 1963.

In 1970, NMFS held a workshop at the Tiburon Fisheries Laboratory to: 1) review briefly the available background knowledge of billfish biology, 2) evaluate data relating to the assessment of billfish resources, and 3) explore the types of cooperative research needed in order to accomplish objectives outlined in 1) and 2).

In order to highlight their importance, a special session on billfishes was held at the 22d Tuna Conference (October 1971) at Lake Arrowhead, Calif. At the conference a series of papers presented on billfishes again reiterated the need for a major symposium to bring together all known information on the subject.

On the basis of these preliminary meetings, NMFS decided to sponsor an international billfish symposium. This was to be the first major symposium organized by the newly created NMFS. In selecting a location for the symposium, the organization committee decided to hold it in conjunction with the HIBT, which is held annually at Kailua-Kona, Hawaii. This joint arrangement had the advantages of 1) having available at the symposium sport fishermen from a number of countries, and 2) permitting billfish specimens to be made available to scientists for research purposes.

Opening Session

Mr. Richard S. Shomura, Cochairman of the Symposium, called the meeting to order and introduced the Honorable Shunichi Kimura, Mayor of the County of Hawaii. Mayor Kimura in his address[1] welcomed the Symposium participants to the Island of Hawaii. He stressed that in developing the islands' resources there is a need for a well balanced mix of indigenous basic industries and scientific research in complementary disciplines. Mayor Kimura mentioned how appropriate in this respect were some of the research projects located on Hawaii, such as those in tropical agriculture, astronomy, geothermal energy, volcanology, and atmospheric sciences. He was delighted that fisheries expertise, in the form of the Symposium and its participants, had come to Kailua-Kona where sport fishing, especially the annual HIBT, is such a valuable part of the recreational and tourist activities.

Mr. Shomura then introduced Mr. Philip M. Roedel, Director, NMFS. Mr. Roedel, in his opening address[2], brought greetings from Dr. Robert M. White, Administrator of the National Oceanic and Atmospheric Administration. This was the first scientific symposium organized by NMFS since its formation in October 1970. The two primary reasons for holding the Symposium were 1) scientific studies of billfishes on a global scale were very limited, and 2) it would provide a forum for interactions between sport fishermen and scientists with regard to a high-seas fishery. Mr. Roedel noted that notwithstanding the long recognized importance of billfishes in worldwide sports and commercial fisheries, we have very little idea of the size of the resource. Published data on the various species are sparse and scattered, and much in Japanese, and thus the Symposium Proceedings would provide the basic background information essential for further detailed studies of the billfishes. Though there are considerable biological, socioeconomic, and politico-legal problems to be solved with regard to billfishes, they are included in only one international group concerned with management, i.e., the ICCAT. Mr. Roedel referred to the occurrence of heavy metals in billfishes and the intense public interest in this aspect, which had prompted the special symposium evening session on the subject. In conclusion, he noted the success of the various cooperative programs between sport fishermen and scientists, especially in tagging, which is important in migration studies of billfishes.

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[1] See Annex 2.

Further addresses[3] of welcome were made by Mr. Michio Takata, Director, Hawaii State Division of Fish and Game, Mr. J. Thomas Stuart III representing Dr. John P. Craven, Hawaii State Marine Affairs Coordinator, and Mr. Peter S. Fithian, Chairman, Board of Governors, HIBT. Mr. Shomura then read the text of a cable[4] received from Mr. F. E. Popper, Assistant Director-General, Department of Fisheries, Food and Agriculture Organization of the United Nations, Rome, Italy.

Dr. F. Williams, Symposium Cochairman, in opening the scientific part of the Opening Session indicated that the intention of the organizing committee was to commence with comprehensive and up-to-date reviews, on a worldwide basis, of the commercial and sport fishing fisheries activities for billfish. The two scientists chosen for this task, respectively Dr. Shoji Ueyanagi and Dr. Donald P. de Sylva, are experts in these fields and share a common linkage with the late John K. Howard with whom they worked closely. Dr. Williams then introduced the speakers, whose presentations are given in full in Part 2 of the Proceedings.

In his review of the commercial fisheries for billfishes, Dr. Ueyanagi stated that the present world production of billfishes is approximately 100,000 tons per year, of which more than 90% is taken by the tuna longline fishery. Japan alone produces about 70% of the world's catch of billfishes and is the principal consumer nation of these fish.

Although billfishes account for only about 18% of the longline catches, they are presently of considerable importance, especially among the fishery products utilized in Japan. Dr. Ueyanagi discussed the value and utilization of billfishes in Japan and described how billfishes have gained status as a quality fish, commanding prices comparable to the tunas. In addition, he described the expansion of the longline fishery, showing that by 1965 the fishery had covered the entire distributional range of the billfishes. Catch and effort data for billfishes indicate that swordfish is the only species which has shown an increase in landings in recent years; blue marlin landings have decreased in the South Pacific, Atlantic, and also, to a slightly lesser degree, in the Indian Ocean, while the catch of the striped marlin has fluctuated greatly from year to year.

Dr. de Sylva stated that sport fishing for billfishes takes place in nearly all warm waters, primarily in tropical and subtropical seas. In probable descending order of relative abundance, the principal species caught by anglers are: sailfish, white marlin, blue marlin, striped marlin, black marlin, swordfish, and spearfish. He then indicated the areas of the world ocean where the most important sport fisheries are presently located. In some regions maximum angling effort coincides with maximum availability of billfish, while in other regions, especially in the western North Atlantic Ocean, Dr. de Sylva stated that maximum angling pressure is correlated with angling tournaments which in turn relate to summer vacations and the tendency of most anglers to fish only during good weather. Angling for billfish during the "off season" may well produce good results in areas which are heavily fished only at certain periods. It seems likely that new billfishing regions can be developed, but this requires the assistance of local governments to provide or insure adequate sport fishing vessels, docks, bait, and, especially, qualified captains and crew.

Dr. de Sylva believes that the relative inefficiency of the gear used by anglers to catch billfish makes it unlikely that angling can seriously deplete the stocks, other factors such as natural environmental fluctuations, pollution, or commercial fishing being equal. There is little evidence that commercial fisheries are seriously affecting the sport catches. An exception is in the eastern Pacific Ocean, where the mean size of sailfish and striped marlin has decreased; these decreases may be attributed to heavy commercial fishing pressure from longline fleets.

The economic value of the billfish sport fishery is extremely important to local communities which support angling activities. In spite of some conservationist feelings promoting release of billfish which are not tagged, Dr. de Sylva noted that catches could be retained for human consumption without seriously depleting the stocks, thus further contributing to local economics.

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[2] See Annex 3.

[3] See Annexes 4, 5, and 6.

[4] See Annex 7.

Officers and Organization of Work

Officers of the Symposium

Cochairmen:
Richard S. Shomura
F. Williams
Sectional Officers:
Section 1. Species Identification
Chairman: William J. Richards
Rapporteur: Izumi Nakamura
Section 2. Life History
Chairman: C. Richard Robins
Rapporteur: Eugene L. Nakamura
Section 3. Distribution
Chairman: Nigel Merrett
Rapporteur: Witek Klawe
Section 4. Fisheries
Chairman: Shoji Ueyanagi
Rapporteur: James S. Beckett
Special Session:
Mercury in Billfishes
Chairman: Peter S. Fithian
Rapporteur: John Baxter
Panel Members: James S. Beckett
Albert C. Kolbye, Jr.
Richard E. Marland
Richard S. Shomura
Cynthia D. Shultz
Special Session:
Sportsmen - Scientists
Symposium Summary: Frank J. Hester
Panel Discussion
Chairman: Dudley C. Lewis
Rapporteur: Peter S. Fithian
Sportsmen: Peter Goadby
George Parker
Richard H. Stroud
Scientists: William L. Craig
C. Richard Robins
James L. Squire
Secretariat:
Robert Bonifacio
Robert T. B. Iversen
Marjorie C. Siu

Organization of Work.—Following the overview papers on commercial and sport fishing activities for billfishes given at the opening session, the Symposium was organized into four sections and two special sessions. The sections covered the fields of 1) Species Identification, 2) Life History, 3) Distribution, and 4) Fisheries. There were 6 papers contributed in Section 1, 13 in Section 2, 10 in Section 3, and 7 in Section 4. A discussion period concluded the presentation of the papers in each section. The first of the special sessions was devoted to consideration of the problems related to the mercury level in fishes and consisted of both formal presentations and a question-and-answer period open to the public. The second of the special sessions was a forum for the exchange of views between sport fishermen and scientists held at the end of the Symposium. It commenced with a summary of the scientific sessions of the Symposium, followed by informal presentations on various billfish topics by a mixed panel of sportsmen and scientists. A subsequent extensive discussion period was open to all.

Sectional Reports

Species Identification.—At this session six papers were presented covering various aspects of the identification of billfishes from young stages through adults, including the fossil record of these fishes. The fossil record is rather scant, with most of the material consisting of fossilized bills. Additional research in this area of study will add greatly to our knowledge of the phylogenetic relationships of these animals.

The identity of adults is quite well understood at this time with the exception of the so-called "hatchet marlin" which occurs in the Atlantic and possibly the Pacific Ocean. Evidence was presented that *Tetrapturus georgei* is a valid species in the Atlantic Ocean. The question of whether or not the blue marlins and the sailfishes in the Atlantic and Indo-Pacific Oceans are distinct species, subspecies, or subpopulations is still unresolved, as is the presence of black marlin in the Atlantic Ocean. Research in the sea area off the tip of South Africa should resolve some of these problems.

Three papers on the identity of the young stages of billfishes emphasized the need for further research, especially the study of variations in morphology. Data were also presented on additional characters which are useful in the separation of the young of Indo-Pacific species. Fruitful avenues for future research were suggested. These included a need for additional material, particularly small juveniles, and a need to rear these animals in the laboratory. The young stages of swordfish are quite well understood and present no problems.

In conclusion, the absence of information on the anatomy of all life stages and of the eggs of istiophorids was commented upon. Further it was stressed that the scientific nomenclature and the common names for these species should remain stabilized and not be allowed to fall into disarray.

Life History.—Thirteen papers were presented in the session on life history. Four papers dealt with the general biology of billfishes: the Atlantic blue marlin around Jamaica (not included in Part 2); the Atlantic sailfish off south Florida; billfishes in the eastern tropical Pacific Ocean; and swordfish in the northwest Atlantic Ocean. Another paper discussed present and future research on billfishes in Australia and New Zealand (abstract only, in Part 2). Three papers dealt with morphology: morphometrics of eastern Pacific billfishes; length-weight data of western Atlantic billfishes; and length-weight relations of central Pacific billfishes. Two papers were presented on mercury content in billfishes: one on northwest Atlantic swordfish and the other on billfishes from Hawaii and southern California. The remaining three papers dealt with various aspects of life history: food and feeding habits of swordfish in the northwestern Atlantic Ocean; maturation and fecundity of Hawaiian swordfish; and gastric ulcers in blue marlin and black marlin from Hawaii.

The papers, and the questions and discussions following the papers, reinforced the belief of biologists that although several aspects of the biology of billfishes are now known, much more must be learned. The life history of any one species is far from being completely known.

Much data have been obtained in the past from taxidermists. The bias of using such data for certain types of studies, such as growth, was explained.

Two papers referred to parasites. The existence of substantial literature on parasites of billfishes was pointed out, along with a need to collate this material.

Attempts at aging billfish by counting rings of hard parts such as spines was reported for Atlantic sailfish and Atlantic swordfish, but no success had yet been attained owing to the inability to determine what length of time a single ring represented.

Pollution was mentioned as a possible factor in decreased sailfish catches off south Florida. Sailfish occur closer inshore than other species of billfishes, and thus could be seriously affected. This was the only time pollution was mentioned.

Distribution.—During this section of the Symposium it became apparent that many facets of research on istiophorids and xiphiids are of interest, not only to the billfish biologists but also to a much wider scientific community. One report contained information which should be of particular interest to zoogeographers; another was concerned with oceanographic studies directed primarily towards billfish biology. In the latter study ocean temperatures were monitored by means of an airborne infrared sensor, and the data obtained proved to be of immediate use to meteorologists, environmental engineers, and other scientific and technical groups.

The Symposium audience was pleased to hear repeatedly just how much the sportsmen have been able to help the scientists. Billfish tagging illustrates this very well. A great deal has been learned about billfishes from recapture of marked fish. Although most of the billfish tagging has been done by sportsmen, the commercial fishery's role in tagging operations cannot be overlooked. Activities of the latter is limited mainly to tag returns, including accompanying data on the fish. Perhaps more billfish could be tagged during commercial operations; this possibility deserves attention from fishery biologists. During the presentation of reports, as well as during the discussion periods, some concern was expressed as to the need for careful planning prior to a tagging program. This is to assure not only maximum inflow of recapture data, but also inflow of data which would definitely aid in analysis of the movements and growth of the fish. An obvious need for better tags, perhaps more sophisticated tags, and better tagging techniques was stressed by several of the speakers. For example, incorporation of tetracycline, lead chelate, or some other compound in the tag could be used to mark time in the bones of the tagged fish and thus aid in age and growth studies by means of hard parts. Most of the participants were greatly impressed with the type of information which results from tracking billfish tagged with the sophisticated "sonic" device described by one speaker.

Billfish larvae caught during various scientific cruises provide us with valuable information of the spawning habits of the adults, as well as on the early life history of the istiophorids and xiphiids. Larval studies are hampered by the considerable difficulties encountered in separating the various billfish species. The only exception is the swordfish which, even at a very early life stage, can be separated readily from the other billfishes. The problem of identification of the billfishes is so great that at the conclusion of this Symposium a 2-day workshop to treat this subject will be held in Honolulu and be attended by several larval billfish experts (Working Party on the Early Life History of the Billfishes of the FAO Panel of Experts for the Facilitation of Tuna Research).

The problem of evaluating the fishing effort related to the sport fishery catch was raised. This is a difficult problem and will be discussed in the following session.

Fisheries.—The papers presented in this section dealt mainly with descriptive accounts of specific fisheries, e.g., the sport fishery in the northeastern Gulf of Mexico, the commercial longline fishery in Hawaii, and the commercial fisheries of Taiwan, and with the presentation and analyses of catch statistics. From the results presented it became apparent that major gaps in our knowledge of billfish biology and population dynamics exist, particularly with regard to age and growth, mortality rates, and stock structure.

One paper specifically examined the interrelationship of the environment and the distribution of striped marlin.

On the basis of data collected to date, much of what we know today of the time and space distribution of billfishes is based on catch statistics collected by the longline fisheries prosecuted by Japan, South Korea, and Taiwan. In addition to being far-ranging, the gear used by the various longline fisheries is essentially the same; thus, the indices of abundance are comparable. This comparability of data was not found to be true for the data collected by the sport fisheries. In the discussion that followed this session, it was recognized by participants that although the sport fisheries for billfishes represents a rich source of good data, biologists are not fully utilizing this source. With a few exceptions, the kinds of catch and effort data collected by individual fishermen, sport fishing clubs, and biologists vary so widely that the data cannot be pooled. One shortcoming noted in sport fisheries data is the lack of recorded zero catches. The importance of this information was discussed in some detail. The need to standardize the collection of billfish statistics from sport fisheries was apparent.

Although the billfish landings in some areas, e.g., Taiwan, showed increases in recent years (possibly reflecting increased effort), the general trends for the several species of billfishes noted in the catch statistics of the commercial and recreational fisheries are downward. In the eastern Pacific Ocean the decline in apparent abundance was especially noted for sailfish. The catch rate dropped from 80 fish per 1,000 hooks in 1963, the first year of substantial longline fishing in the major sailfish grounds of the eastern Pacific Ocean, to 11 fish per 1,000 hooks in 1970; a decline of 86%.

Similar declining trends of billfish catches were reported for other areas of the world by Dr. Ueyanagi in his review of the world commercial fisheries for billfishes presented during the opening day's session.

Special Session: Mercury in Billfishes

This special session began at 2000 on 10 August 1972, at the Hale Halewai in Kailua-Kona, Hawaii. Approximately 150 people attended; participants were mostly from the sport fishing fraternity. The purpose of the session was to provide participants in the HIBT and the interested public with the latest available information on the problem of mercury in fish and the opportunity to discuss the situation with experts on the subject. Presentations were made by the five panel members; two were summaries of scientific papers given at the International Billfish Symposium; two described work done in the State of Hawaii; and the fifth featured Dr. Kolbye, who described the effects of mercury on humans, the role of the FDA, and the rationale for its guideline level of 0.5 ppm mercury in fish.

Presentations

James S. Beckett
"Mercury in Northwest Atlantic Swordfish"

Mr. Beckett reported that Canada banned the sale of swordfish in 1970. Up until that time the annual swordfish landings in Canada amounted to about 8 million pounds valued at $4 million. Beginning in July 1971, a vessel of the Fisheries Research Board of Canada conducted longline fishing from Cape Hatteras to the Grand Banks to obtain swordfish for analysis of mercury levels. During cruises in July and August 1971, 210 swordfish (lengths ranging from 74 to 247 cm fork length) were taken. Samples of dorsal muscle analyzed for total mercury showed an average of 1.15 ppm and a range of 0.09-4.9 ppm. Differences in mercury level were noted between females and males as well as between tissues; liver and kidney had higher levels than brain tissue. Mr. Beckett reported that swordfish appeared to pick up mercury in southern areas and lose it during the summer on the feeding grounds in northern areas. His conclusion was that the source of mercury is volcanism in tropical areas and that mercury is being picked up by fish through the food chain. The full text of this paper is included in Part 2 of the Proceedings.

Richard S. Shomura
"Mercury in Several Species of Billfish
Taken Off Hawaii and Southern California"

Mr. Shomura noted that since December 1970, when the subject of relatively high mercury levels in tunas and swordfish became news, NMFS has had an ongoing sampling program to determine the mercury content in several important sport and commercial fish and invertebrate species. The 56 striped marlin taken from waters off southern California and Hawaii and analyzed for total mercury ranged in size from 56 to 231 pounds (25.4 to 104.8 kg). The total mercury levels for white muscle tissue varied from 0.03 to 2.1 ppm; there was no obvious relationship with size of fish. Although the white muscle of 37 blue marlin also showed a wide variation, a trend of an increasing mercury level with increasing size of fish was noted. The mercury levels ranged from 0.19 to 7.86 ppm; fish size ranged from 96 to 906 pounds (43.6 to 411.0 kg). Mr. Shomura reported that the total mercury levels in blue marlin livers ranged from 0.13 ppm to a phenomenal high of 29.55 ppm. He stated that a comparative study of identical tissue samples analyzed by two laboratories showed wide variations in results; one laboratory reported higher values consistently. He concluded by stating that the NMFS program was collecting mercury data as it relates to the fishery resources and was not presently addressing itself to the effects of mercury on mankind. The full text of this paper is included in Part 2 of the Proceedings.

Cynthia D. Shultz
"Total and Organic Mercury in Marine Fish"

Ms. Shultz reported that a part of their mercury study was concerned with determining the proportion of methylmercury in billfishes. A large number of marlin samples obtained with the assistance of NMFS were analyzed at the University of Hawaii laboratory and also analyzed by an expert in Sweden; the results of the two sets of analyses agreed very closely. Mercury levels in the billfishes ranged from 0.35 to 14 ppm. Of the total mercury, organic (methyl) mercury constituted a small percentage (up to 10%). One example, a 155-pound (70.3-kg) fish, contained 4.1 ppm total mercury and of this 0.54 ppm was organic mercury. A regression analysis of all samples tested showed an asymptotic level of 1.55 ppm organic mercury. Ms. Shultz noted that their studies indicated an upper level to the amount of organic mercury accumulated and theorized that any amount over and above this level was transformed into inorganic mercury and excreted. She also theorized that mercury in billfishes originates from natural contamination, possibly of a volcanic origin; however, much more work needs to be done in this area. This paper authored by J. B. Rivers, J. E. Pearson, and C. D. Shultz has been published in the Bulletin of Environmental Contamination and Toxicology 8(5):257-266, 1972.

Albert C. Kolbye, Jr.
"Potential Health Hazards of Mercury in Fish"

The full text of this presentation appears as Annex 8 of this volume.

Richard E. Marland
"Status of Mercury Studies in Hawaii"

The full text of this presentation appears as Annex 9 of this volume.

Discussion.—The following includes some of the more significant questions asked of the panel by the audience, and the panel's answers.[5]

George Parker (Kailua-Kona, Hawaii):
Ms. Shultz referred to fish tolerating a certain amount of methylmercury and then possibly converting it to another form of mercury which is excreted. Might this follow with humans?

Ms. Shultz:
We don't know the answer. Our data merely indicate that biotransformation may be taking place.

Captain Parker:
Does methylmercury keep being accumulated?

Dr. Kolbye:
The biological half-life of methylmercury is 70 days; to stay below the safe blood level the intake of methylmercury should not exceed 30 micrograms per day.

James Delohery (Australia):
Would you comment on selenium detoxification?

Mr. Beckett:
There was some work that suggested that selenium may reduce toxicity of mercury; however, more work is needed.

William F. Royce (NMFS, Wash., D.C.):
Why did FDA impose a prohibition on the sale of fish with mercury levels over 0.5 ppm rather than merely warn the public such as is done with other products containing poison?

Dr. Kolbye:
The public has a varying understanding, a varying consumption rate and therefore FDA determined that a guideline was necessary in the interest of protecting the public. With respect to swordfish, 95% of the samples exceed the guideline. There are also FDA guidelines for other food items and toxicants.

Witek Klawe (IATTC, La Jolla, Calif.):
Would you comment on various articles criticizing the mercury guideline?

Dr. Kolbye:
FDA is prepared to defend the guideline.

Dudley C. Lewis (Honolulu):
Why were there no public hearings held before the guideline was set? Were any of the deliberations made public? Was the guideline politically motivated?

Dr. Kolbye:
Many guidelines do not require hearings. The guideline was reviewed extensively within FDA and by a panel of 12 experts. Testimony was given before the U.S. Senate. Scientific documentation was presented in the Journal of Environmental Health. I don't know if this is considered making it public. The question as to whether the guideline was politically motivated is ridiculous.

Richard F. MacMillan (Honolulu):
People have been eating marlin in Kona for generations with no ill effects. Therefore, I question Dr. Marland's statement that years and years of work is needed to come up with an answer. What is your reaction to the situation in Kona?

Dr. Marland:
There is no evidence of damage from eating marlin in the United States. However, there has been no systematic search for subclinical symptoms. Studies by trained medical doctors to look for subtle symptoms would be highly desirable; however, it cannot be done quickly or cheaply.

Richard H. Stroud (Sport Fishing Institute, Wash., D.C.):
Is the 0.5 ppm guideline for total mercury? In view of recent findings regarding methylmercury not constituting 100% of the mercury present, shouldn't the standard be for methylmercury?

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[5] For purposes of brevity, the question and answer section has been abbreviated and in some cases paraphrased.

Dr. Kolbye:
The guideline is for total mercury. Methylmercury is the dangerous form, but much needs to be learned about the toxicity of all forms of mercury found in fish. It would be of interest to determine the exact chemical form of the nonmethylmercury part found in marlin.

Fred Rice (Kailua-Kona, Hawaii):
Regarding the University of Hawaii study—was mercury added to the feed of the swine? If the swine were fed marlin without the added mercury part, would there be any effects?

Dr. Marland:
Yes, mercury was added. No, they showed no effects if mercury wasn't added; however, controlled experiments are needed. It is not a question of just feeding marlin containing mercury without experimental controls.

Mr. Rice:
Is there any information available on what is being done with the marlin being caught? My guess is that probably 90% is being consumed by humans. Does the FDA have authority to intercede in cases where the fish is caught in Hawaiian waters and consumed in Hawaii?

Dr. Marland:
We don't know the disposition of the marlin caught. The guideline is a responsibility of the Director of Health for the State of Hawaii.

Question:
Has the economic impact of setting the guideline been considered?

Dr. Kolbye:
With the public health at stake it is necessary to act quickly. Severe cases in Japan showing diffuse brain damage give good cause for such a guideline.

Richard E. Young (University of Hawaii):
Would you comment on the case of the woman in New York who suffered mercury poisoning?

Dr. Kolbye:
Apparently this woman consumed swordfish daily; however, this cannot be fully documented.

Captain Parker:
Sweden made a mistake in calculating their guideline. Has anything been done to change it?

Dr. Kolbye:
They have not changed their guideline. Sweden has taken the following steps: (a) they close certain streams, (b) they advise that no more than one meal per week of fish from certain areas be eaten, and (c) they advise pregnant women not to eat certain fish.

Captain Parker:
How much trouble would it be to take samples of the dorsal muscle and determine the mercury level?

Mr. Beckett:
It would be extremely expensive—about $1,000 per sample.

Ms. Shultz:
The amount of money is not the problem—time is—it requires 45 h to process each sample.

Captain Parker:
Is it true that broadbill swordfish landed in California are sampled for mercury and can be sold if found safe? What is the form of the FDA ban?

Dr. Kolbye:
Regarding swordfish in California, as far as I know, they are being handled as you have noted. The tuna and other industry people are cooperating in conducting such monitoring programs. It may be possible to do this for marlin; however, it must be done by an accepted laboratory to assure that it is done correctly.

Captain Parker:
What did the general public hear with respect to marlin in Hawaii? Are we breaking the law if we give away fish?

Dr. Marland:
The Director of Health in Hawaii publicized the fact that the marlin contain unsafe levels of mercury, and received a voluntary withdrawal of billfish from the market. If fish are given away it breaks the gentlemen's agreement. If the fish are not fit for human consumption, they should not be given away or eaten under any circumstances.

Peter S. Fithian (Honolulu):
Throwing away fish is a philosophical problem. We have run out of time. Thank you all for attending and contributing to this most worthwhile discussion.

Special Session: Sportsmen—Scientists

Symposium Summary (Frank J. Hester, USA).—Dr. Hester provided the sportsmen-scientist gathering with a summary of the results presented at the scientific sessions and the special session covering mercury in billfishes. His presentation was made with the aid of a number of slides which were used by the various speakers. Since Sections 5 and 6 include summaries of the sessions, and the full text of the papers is given in Part 2, only Dr. Hester's closing statement will be included here. It follows:

I would like to make some general comments. Billfishes, because of their size and scarcity, are very difficult animals with which to work. It is very difficult to find fresh material and even more difficult to find living material. These are probably the main reasons why today the state of knowledge of billfish biology is really not very far advanced. We are certainly always very grateful for the opportunity to take advantage of a tournament like this, where one can actually see the fish when only a few hours old. This, along with the logbook recording, the cooperative tagging programs, and the information from the commercial fisheries probably is going to mean that in the next decade we will begin to understand these animals much better. To bring about this understanding will require considerable work on the part of the angler, who will have to be prepared to keep detailed records, and either mail them in or have them delivered at dockside. You will also have to put up with the occasional biologist "poking around" your fish. Finally, you should be prepared to change to the metric system of measurements in the very near future and this means you will have to rewrite the International Game Fish Association (IGFA) world records. Thank you very much.

Panel Presentation (R. S. Shomura, Symposium Cochairman).—I would like to start by stating that we are extremely fortunate—and I think this was excellent planning on our part—in having as Chairman of this morning's Sportsmen-Scientists Panel Session Mr. Dudley Lewis, who took the winning prize in this year's HIBT tournament. It is also fitting that he assumed the post as Session Chairman at this closing meeting, since he is the only sportsman-angler who has participated in all 14 of the HIBT tournaments. Mr. Lewis was born in Hawaii some few years ago and has been fishing all of his life. He is presently a practicing lawyer. It gives me great pleasure to introduce Mr. Dudley Lewis.

D. Lewis (Chairman)

Ladies and gentlemen, the format of the Symposium this morning is the following. We have with us three sportsmen and three scientists and I will call alternately on each of the scientists and sportsmen to make a short statement. At the conclusion of their remarks we will welcome questions either from the panel or from the audience. First, I will call on Dr. C. Richard Robins, University of Miami Professor, who has done a lot of research on billfishes, to give you some idea of his work and what can be done to further the dialogue between scientists and sportsmen.

C. R. Robins

I want to start not with an account of what I or my colleagues have done at the University of Miami, but with some of the problems that we run into in dealing with billfishes and what we need in the way of information.

Firstly, we have lost much valuable data from the photographic record that would have otherwise been available to us. If one goes to any of these tournaments, one cannot help but be impressed with the number and quality of the cameras but, from our standpoint, many of the photographs are of poor quality. Of course, we have nothing against the types of photographs that you want for your own records, but Don de Sylva and I very frequently are called upon to identify fish from photographs. It is extremely difficult to do so when the fish is hanging up and the cameraman is very close causing foreshortening, which jeopardizes our obtaining good body proportions. Very often the angler, the captain, or mate will have his hand over some very critical character such as the dorsal or pectoral fin. In taking photographs this is really what we need. First of all I think that every photograph should have a small identification tag with it—it can be just a piece of paper like we've had at this tournament—which indicates the locality of capture of the fish, the weight, and the length. Photographs have a habit of going astray for many years and then we get a whole pack from a person saying, "I think this is a fish I caught off Malindi, Kenya," when in fact it may have been one that was caught at Bay of Islands, New Zealand. This leads to difficulties, so if you have an identification tag as part of the photograph there is never any question about the origin of the fish. The next thing is to try to take the side view of the fish with as little distortion as possible. It is often very easy to get to the tower on your boat and shoot a picture of the fish in the cockpit with very little distortion. In other cases it is very simple to allow the fish to hang, as you often do here at Kona, then back off and take a telephoto shot of it and this reduces the distortion.

In addition to the side view, it would be very helpful to take a picture of the underside of the fish, at least from the area of the anus forward. The position of the anus relative to the anal fin is very different in the different kinds of marlins, especially in the Atlantic Ocean. In the spearfish the anus is very far forward, in the white marlin it is very far back, and in this new species we call *georgei* it is in a sort of in-between position.

This undershot can also show the very important shape of the pectoral fin. Marlins are wonderful machines, being really well adapted for high-speed swimming in the ocean. The blue marlin, as you know, maintains its depth a long way aft, so if you take the center of gravity of this fish, it is fairly far back. These animals can swim along very efficiently and they keep their pectoral fins pretty much back toward the socket. The black marlin has its weight far forward and really is front heavy. If you could cut the pectoral fins off this fish, it would pitch and go right down toward the bottom. Its pectoral fins are therefore actually stabilizers. If you look at the cross section of the pectoral fin of a black marlin it is very different from that of a blue marlin, being shaped like the cross section of an airplane wing. This fish really flies through the water and gets lift to compensate for pitch. The pectoral fin alone can distinguish the blue marlin from the black marlin, and yet in many photographs Don de Sylva and I are unable to tell anything about the pectoral fin because the fish is hanging up and the fin very commonly will flop down. The shape of the dorsal fin is also important.

I think it really doesn't cost very much to take three photographs, one of the whole fish, one from underneath, and one close-up view of either dorsal fin or the pectoral fin. But don't forget the identification plate with the geographic information on it as a permanent record.

I would like to direct this next remark mainly to the scientists. If you ask anglers to do something, then you should give them specific instructions as to what it is you want, and when you do this you assume certain responsibilities. Nothing makes me madder with scientists than to have one of my colleagues commit anglers to doing something and then never follow-up on it. I've seen the late Al Pfleuger of Miami spend a lot of money, and an awful lot of time, gathering data for some biologist and after he did all of this nobody would show up. I think this is the kiss of death in cooperation. If you ask anglers to do something, you have an ethical responsibility to pick up the information and to provide them with some sort of a report on what it is that you have done with it.

D. Lewis

Thank you very much, Dick. I will call next on Peter Goadby, an outstanding sport fisherman and author who has traveled all over the world.

Peter Goadby (Australia)

Australia's offshore game fishermen have always been proud of the fact that they have cooperated actively with scientists. Being somewhat isolated, we have realized that the sport fisherman is in a unique position to help the scientist because they are the only ones that can help us with things we are unable to learn. If we record data accurately then the scientist can give us a lot of help. We are as proud of our contribution to the "establishment" with the capture of blue marlin at Cairns last season as with the 10 marlin we caught averaging 1,000 pounds each. We are fortunate in Australia at the moment that in addition to the various government agencies and institutions, there is a well-founded university coming into being at Townsville just 250 miles from the Cairns marlin grounds. There is every indication that some research on the black marlin will be undertaken at this institution.

The cooperative tagging program in Australia has had remarkable growth, and as an Australian fisherman I take my hat off to NMFS for the assistance they have given us. It gave us pleasure slamming a tag into a fish knowing that the tag had come from the United States and that the information would come back perhaps from a Japanese or Taiwanese longliner through the United States. This really made us feel we were part of a worldwide program. The growth of tagging in Australia is interesting as 10 yr ago there were probably no more than two or three fish released in any one season and recoveries were nil. As you have already heard, there have been two black marlin recoveries already. The first fish was out approximately 360 days and was returned only 100 miles from where it had been tagged. The second one, 1 of the 169 fish tagged at Cairns last season, was out only 110 days but had traveled something like 1,440 miles in that time. Tagging is now being started in New South Wales and later we will have the help of anglers even farther south. The program will be not only on marlin, as we are encouraging anglers to tag and release every kind of fish including offshore species of sharks like hammerheads, makos, and blue sharks. We are not really encouraging the release of white or tiger sharks, because we feel if someone got "chopped up" on the beach and a tagged shark was caught we would certainly be in trouble.

Anglers in Australia have long shown their interest in cooperating in any overseas programs. We were most happy to cut the pectoral girdles from black marlin to send to Dr. Robins, and to provide data on the blue marlin in the Pacific. We would be most happy to give any help we can on the size and movement of the black marlin, or anything else anyone wants to do on that species. The same applies to any studies on sharks. We still have a lot of dangerous species of sharks in Australia, and if anyone is interested in them we would be happy to help. As I said previously, this meeting of fishermen and scientists is really great, and I believe the best thing that has happened in sport fishing probably in the last 100 yr. We have always known the names of a lot of scientists, and I guess similarly the scientists have always known the names of a lot of interested charter captains and interested sport fishermen. Now we have got names to go with the faces and faces to go with the names, so let us all keep in contact and go forward from here on.

D. Lewis

Thank you very much, Peter. I shall call on Mr. William Craig, formerly with the California Department of Fish and Game and now with NMFS.

W. Craig (USA)

I obtained my experience with the billfishes, primarily striped marlin and broadbill swordfish, during my time with the California Department of Fish and Game. My main responsibilities were to other major programs and moving around in the billfish fishery was quite incidental and confined simply to compilation of adequate catch statistics for these two species. The mercury problem last year finally gave me an opportunity to join the "blood-and-guts" detail and to see what a striped marlin looks like. I had, of course, every cooperation from the local sport fishing clubs in California, as otherwise it would have been a monumental task to try to gather all these specimens of striped marlin for determination of mercury content. I might go back and say it was a mandate from the big-game sport fishermen in southern California that made the Department undertake a program to try and clarify the situation with regard to mercury. We collected striped marlin samples and delivered the results of the mercury analyses to the sport fishing clubs. Cooperation can be obtained from sport fishing clubs by working with them but reiterating what Dick Robins said, do not ask for something unless you can follow up on it.

Additionally, I would like also to indicate the value of club yearbooks. Some clubs just report their annual catches and their annual buttons and awards, while others present historical data on catches and incidents that took place. One particular club yearbook contains a couple of articles by lawyer members that contribute much to our knowledge. I wish to call these types of publications to the attention of scientists because there is certainly a great deal of merit in what the sport fisherman has to offer from his on-the-spot observations. I brought these particular two yearbook issues for Dr. Ueyanagi, because they contain some data on the marlin weight-frequency distributions in the southern California fishery. These data were collected since the publication of his joint paper with Colonel Howard. My small mercury program last summer, which was just a "news note," was picked up and published in this little booklet. If club articles warrant it, and are called to our attention, perhaps we can see that they obtain wider distribution than the clubs themselves can provide.

D. Lewis

Thank you very much, Bill. I next call on Mr. Richard Stroud, the Executive Vice-President of the Sport Fishing Institute, who will make some remarks on the role of that organization.

R. Stroud (USA)

It's a great pleasure to be here, first because it's the first time I have ever been to Hawaii and secondly, because I guess I am unique at this gathering since I am the only official "hybrid" to appear before you. Although I am sitting on the sportsmen side it is hard for me to determine whether I am really a sportsman or scientist—perhaps a little of both. I have worked in both areas and I enjoy and participate in sport fishing to a great degree. Nevertheless I would like to take a little time to acquaint you with my organization. On the table I have put some propaganda which explains the nature and purpose of our organization and also some application blanks. I have also prepared a few mimeographed comments on the role the Institute has played over a long period of time and I invite you to take a copy later.

The Sport Fishing Institute is the only national nonprofit, tax-exempt conservation organization devoted wholly to the conservation of fisheries resources, and it was designed to help fishing and, consequently, fishermen. It was established in 1949 and functions as a research, education, and professional service type Institute, and is staffed entirely by fisheries scientists. It was designed to be a catalyst for development and promotion of the application of all types of progressive fish conservation programs in order to enhance the sport of fishing.

In the course of general overviews of fish conservation it became very apparent, a couple of decades ago, that very little was being done in the inshore area between the seashore and the high seas. The existing institutional agencies were concerned either with inland types of resources or high-seas resources. There was real diversion of interest away from the very critical and sensitive area of the coastal zone and estuarine areas which are vitally important to the continued survival of many of our game fishes. Consequently, we attempted to stimulate a lot of activity in this area and founded a research program of our own, small in size but designed to stimulate interest. I think we were successful in doing that. We began making grants as early as 1952. Our first research grant in the billfish area was a small one made in 1958 to an investigator at Yale University to work at an east coast tournament similar to this one. We made a follow-up grant later to South Carolina University in 1959 to develop further studies on the life history of the blue marlin and white marlin. Then we became interested in the work that Frank Mather was doing at Woods Hole, the Cooperative Game Fish Tagging Program, and for more than a decade have provided small but continuing annual support to that program.

Based on the research we have done, and the obvious problems and needs that existed, we felt it was necessary to enlist the support of the Federal and State governments as much as possible. We have great interest in the Dingell-Johnson Program, which is supported by an excise tax you pay when you buy a reel or big rod. These funds are channeled to the States, which were stimulated to use some of this money for marine game fish research, but there was nothing being done at the Federal Government level. The then Bureau of Commercial Fisheries was interested almost exclusively in the high seas. So we drafted a bill, which eventually became known as the Marine Game Fish Research Act and this was passed in 1959. This marked the formal entry of the Federal Government into this area of concern which had been previously neglected.

Early in the 1960's, as you are all well aware, Japanese longlining exerted fishing pressure on the stocks with an evident adverse impact on sport fishing. I am not going to go into that as the analyzed data and results are well known. In any event it was decided to hold a meeting in Rio de Janeiro in 1966 to consider the formation of a conservation organization to be concerned with research and management of the tunas and tuna-like fishes of the Atlantic Ocean. I was fortunate enough to be an advisory member of the U.S. delegation, together with a representative of the Bureau of Sport Fisheries and Wildlife (the late Albert Swartz).

Preceding the Rio conference, a series of meetings was held with representatives of sport fishing interests nationwide, at which we tried to determine the course of action we might possibly pursue in Rio. We decided there were several things we ought to do. First, and most important, we sought to have a separate meeting with representatives of the Japanese delegation, particularly the private individuals representing the commercial fishing industry. We sought four objectives: 1) recognition that there was a significant problem of mutual concern due to the longlining activity; 2) agreement that the longliners should remain a sufficient distance from billfish sport fishing centers to preclude direct conflict; 3) an agreement that eventually there would be convened an international scientific conference on billfish biology; and 4) management following not less than a decade for research.

The Rio conference resulted in the establishment of the International Commission for the Conservation of Atlantic Tunas and this also embraced responsibility for research and management of billfishes. The conference also provided the hoped-for opportunity to talk with Japanese commercial fisheries interests. As a result the objectives that I have outlined were substantially agreed to and, in return, the U.S. sport fisheries representatives agreed to promote cessation of destruction of Japanese longline gear.

Following the conference, we came back here and held a series of meetings across the United States with representatives of sport fishing groups promoting this latter part of the agreement. Obviously, if you are going to get something you have to give something in return and it seemed to us that this was a very reasonable arrangement. Until recently, aside from a few temporary minor relapses, matters seem to have worked out well since conclusion of the agreement at Rio. Several incidents have occurred, though, which underscore the usefulness of the agreement. In the spring of 1967 for example, my organization formally requested that the Japanese overseas trawlers association revise previously announced plans for exploratory trawling along the east coast of the United States. As a result of several exchanges of correspondence, these plans were substantially altered so as to operate in waters north of the Miami-West Palm Beach area in Florida, and offshore, well beyond the range of the 1-day charter trips out of the more important angling ports along the Atlantic Coast from Florida to Eastport, Maine. Last year several Japanese longliners commenced fishing in the Gulf of Mexico, and are continuing to do so this year, and have come into conflict with the long range, private charter sport fishing craft characteristic of that area. There was a flurry of excitement over an alleged mass harvest of billfishes based on shark fins, hung to dry in the superstructure of a Japanese ship being misidentified as marlin tails. I had it on the best of authority from NMFS people that these were indeed shark fins. This point was cleared up, but the longliners remained sufficiently close inshore to come into occasional contact. I understand that some of them have drifted even beyond the legal limit in the past few days, perhaps accidentally. Based on documented data provided by the Coast Guard on request, and also through the help of NMFS, we relayed this information to our Japanese contacts and suggested that they have a special problem in the Gulf of Mexico. We urged that they instruct their fishermen, if they intended to continue implementing our unofficial agreement, to move farther back offshore. As yet, nothing has been done but we have some information which suggests such instructions will be forthcoming.

It seems to me that it is highly desirable that "environmentally concerned" sport fishermen refrain from the destruction of Japanese longline gear. I cannot emphasize too strongly that if there is to be any kind of a quick settlement to the benefit of American sport fishermen, then we have to hold up our end of the bargain. If it turns out that the Japanese have decided to abrogate the agreement, then we will have to see what other measures may be taken. I am not convinced yet that the agreement is without viability at this time and I believe that we should do everything we can to show we are holding up our end of the bargain.

I want to put in a special plea in terms of the official role I am supposed to fill here. As far as sportsmen are concerned, I think one of the things you must do, if we are going to find out enough about billfishes to eventually hold out hope for a bilateral treaty conference with the Japanese and to work out an international rational management plan for these fishes, is to provide money for this research. I do not necessarily mean directly, but at least indirectly, through support of appropriations to the agencies who are doing work. Obviously this is very expensive research, and you have had examples of it here. For example, if we are going to build saltwater study lakes to support adult black marlin as we have heard suggested, I can see that it is going to be fantastically expensive! Even when we are talking about $120 tags, that also is pretty expensive. I think there is going to be a great effort made on the part of the Federal Government (NMFS) to show they are spending an awful lot of money right now on billfish research. They are going to take all the different pieces from existing programs with commercial fisheries activities and say "this is what we are doing and we are doing a good job." But what we want is additional research if we are going to have answers to these problems. We have got to have additional money to do it and that has got to come out of appropriations made by the Congress.

I can tell you right now that the Congress is not very sympathetic and this means you are going to have to get some political pull behind this thing. You are going to have to write your congressmen and tell them to give these boys (NMFS) the money. Our organization will try to spread the word when appropriations time comes around. From the standpoint of the scientists, obviously, I think we want them to do the work and provide the information that's necessary to come up with the rational management programs. However, I think I would suggest at this time that, philosophically, the scientists are going to have a very difficult problem. They have based most of their work in the past on the concept of maximum sustainable yield, having been trained this way, as this has been the cornerstone of commercial fisheries management. I submit to them that this has been an inadequate philosophy for rational management of sport fisheries.

D. Lewis

Thank you very much, Dick. I now call on Mr. James Squire, who is a fishery research biologist with NMFS in La Jolla, Calif.

James Squire (USA)

I am with NMFS in La Jolla though formerly I was at the Tiburon Laboratory. You heard Dick Stroud state that about 1960 the Marine Game Fish Program was established and one of the laboratories that it had started was at Tiburon, Calif., with which I became associated in 1960. This laboratory was exclusively for marine game fish and this function shifted to NMFS in 1970, when there was a revision of programs. I moved down to La Jolla with a program to study billfish migrations through the tagging programs in the Pacific Ocean area.

There is concern for the billfishes in view of a new increase in the utilization of these resources as indicated by actual decline in the worldwide catch of billfishes. As Dick Stroud pointed out, if you are to attempt to manage this resource you must certainly take into account the needs of the users, both sport fishing and commercial. We manage these things in different ways, the commercial fishery on maximum sustainable yield and the sport fishery on large numbers of big fish. These two concepts are in conflict and will certainly have to be resolved in the future.

In 1961 we became involved in billfish research in the eastern Pacific Ocean, primarily life history work and the tagging program, looking forward to the day when such information will be needed to make rational management decisions. We indicated at this meeting the problem of obtaining good catch and effort data and this is a field where a sportsman can contribute greatly to research. We get good catch and effort data from the Japanese commercial longline fisheries throughout the world but the collection of similar data from sport fisheries is very poor. What is needed is better fishing logs, and people must be willing to carry them and fill them out to the best of their ability.

The purpose of all this catch and effort data is to show effectively the catch rate in the sport fishery and how this is possibly being affected by changes in the catch rates in the offshore commercial fisheries, which sample a greater number of fish throughout the eastern Pacific Ocean. I think we can say that the sport fishery probably takes about one twenty-sixth the amount of fish that the commercial fishery takes in the eastern Pacific Ocean. Despite these good data from the commercial fishery, one needs to know how it is affecting the sport fishery if one is involved in any international negotiations. You have to have the scientific proof. This is the reason for encouraging sportsmen and clubs to keep better records of catch and effort. Not only are we interested in the days of fishing with catches, but we are interested also in the number of days when people go out and do not catch fish. Using only days of effort which produce catches does not give a true measure of what is actually going on.

We certainly need more data on environmental factors such as temperature and water color. As F. Williams said here yesterday we are studying a living animal in a moving environment and everything is changing from day to day. We need to know how billfish move in relation to the environment because this may tell you why you are not catching fish. There are possibly two reasons, either the environment is not right for the fish, or the year class strength is low and there are not many fish around. To determine which of these factors is more important we must know something about both.

We need to know more about migration patterns which sportsmen have assisted us with in the past and are continuing to do. We must define the normal range of the fish in the ocean, as this has a very definite influence on the type of management you might use for the resource. For instance, in the albacore fishery of the North Pacific Ocean you can take fish off Catalina, Calif., and then some 5 mo later they will be south of Tokyo, Japan. You certainly cannot just manage the fish off California, as the resource is ocean wide. This is why migration studies are important. Another example would be the yellowfin tuna in the eastern Pacific Ocean. Scientists have tagged many thousands of them and found a north-south migration pattern with very little east or west movement, so they drew a boundary line at long. 130°W. Does this hold for billfish or are they transpacific migrators? This is one of the reasons for starting the tagging program.

I think sportsmen realize we have a high mortality rate with tagged billfishes, but they are still willing to tag these fish. I see a challenge here to the sportsmen to find better ways of hooking fish or getting them alongside so that they can be more easily tagged, thereby reducing mortality from this cause. At present the only way to catch billfish is by hook and line either with the longline or rod and reel. An exception is by harpooning them and that is not very satisfactory for our purposes.

We need to know the economic value of sport fisheries. The billfish catch by sportsmen is not great, but the sportsmen spend a lot to catch them.

The sportsmen, as Dick Robins said, assist us in the collection of biological data but there is one thing that I think they could collect in addition to weight, and that is length; of course, some do this routinely. We should also collect data on the sex of the fish and this is not so difficult. In summary, we should give a little training and urge the marine game fishermen to take an interest in the billfish resources and the future management of them. As Dick Stroud pointed out this needs funds not only from our country but from other countries around the Pacific Ocean (and worldwide). These countries or states should be encouraged to conduct additional work on the billfish resources off their coasts. I urge the marine game fishing world as a whole to get a copy of the Proceedings of this meeting and to read it, because I think you will find we have summarized just about all the knowledge on billfishes worldwide. Hopefully this will give us a better informed and enlightened marine game fisherman geared for the billfishes.

D. Lewis

Thank you very much, Jim. Our last panelist is one that I am sure you all know. You have certainly heard about him, he is one of the pioneer charter captains of Kona, he's been at it a long time, he is knowledgeable, and it gives me great pleasure to present another good friend of mine, George Parker.

G. Parker

Thank you, Dudley. I am a charter boat skipper and I think I have been at this for 28 yr now. This year I am president of the Kona Charter Skippers Association which comprises some 18, possibly 17 boats now that we lost a boat last night in the Kona area. I have just thought of a real good reason for all of us being here, in addition to the reasons that are quite obvious. It is said that this globe is covered three-fourths by water and only one-fourth by land, and it is for sure the good Lord intended for us to spend three-fourths of our time fishing and the balance ploughing.

I cannot tell you how excited I am about this meeting. Kona is just bursting its seams with scientists and other people knowledgeable about billfish; all kinds of fish for that matter. I want to emphasize that Kona is certainly proud to have you all here from all over the world for what I understand is the first ever Billfish Symposium. The Charter Boat Association, which I represent here this morning, could not be happier about this event.

It has been said that it is important that the charter boat captains and crews, as well as the private sport fishermen, realize that they can be a very great help to the scientist. They should be alert and report the things they see, the things that happen aboard the boat relating to fish, water currents, temperature, and other conditions of interest. For example such facts that one day we see thousands of porpoises then the next day there isn't a porpoise near the boat. Or when the humpback whale comes down here what happens then? Does he scare off all the marlin? Do the currents make that much difference to our fishing? We all encounter these things when we're at sea but we don't record them, and although we talk over the Citizen Band (CB) radio to each other about what we think the current is doing and why we are, or are not, catching fish, it never seems to get beyond our association and our daily conversations.

Possibly one result of this meeting and what's been said here this morning might bring about a form that we could have aboard each charter boat to be filled out. We have plenty of time between strikes and it doesn't have to be something to be done after you get home when you're so tired and can't think straight. We all have writing space aboard our boats. We could have a pad of forms to fill in, even if it's virtually reduced to a form where you just check off the items as you go down a list. At least we have to do something more than we're doing at present. We've got to help the scientists with our firsthand knowledge. We're out there on the grounds rather like a weather ship out on the channel that reports the weather as it comes through, so we are the outposts and we have to respond about fishing. At the coming meeting of the Charter Skippers Association we are going to have some time devoted to the form of help we can offer to the scientists and in turn to ourselves. The realization of what we can do has been growing. Even before this Symposium some of our skippers have been recording certain types of information. It even occurred to me to put a tape recorder aboard my boat and tape what comes in over the CB. This could be one way of starting a record of daily fishing conversations; possibly some one on the shore, who has a good CB radio could tape record some of the fishing conversations that go on off the Kona coast.

We are so fortunate here to have a calm, comfortable sea to fish in and some days with a lot of fish. I wonder if we realize how lucky we are. Most good billfishing areas are so rough that you are standing on your beam ends and yet people still go out fishing for them. I would say we are spoiled here with our lee shore that extends out so far that 95% of the time we hardly have a whitecap. I think the 5 fishing days of this tournament have shown people what the Kona coast can be like and why it's so easy to enjoy a day at sea and land a billfish, if you're lucky enough to hook into one.

Lately we have heard a lot of discussion on conservation of fish and possibly the mercury in billfish scare has emphasized this. The belief is now that there is a dangerous level of mercury in the blue marlin and here in Kona we catch more blue marlin than anything else. As I have said before, and I will say again, part of the revenue in the charter service is the sale of fish, if and when the angler leaves it with the skipper. We depend on that sale and it has been some help in holding down our charter prices and without it we are seriously hurt. The blue marlin revenue is shared between the skipper and the crew and some of the boats have gone out of service because they could not take that decrease in the share of the profit. However, it is an ill wind that does not blow some good, and here the good is concerned with conservation of billfish.

I think it's a general trend at Kona that if a person catches a billfish and it is his first fish, we usually keep the fish because the ego has to be built up with a photograph of the fish hanging at the dock. We can well understand that and it is worthwhile, as well as a beautiful advertisement for the Hawaii tourist industry. So we take that first fish, but how about the second and subsequent fish? The skipper and crew ask the angler if it is just another fish as far as he is concerned or does he care to have the fish mounted. This may be a little expensive for him so they ask if he would like to release the fish and let him fight again. The angler often agrees. Of course there is always the person who can afford to have the fish mounted, so the fish is landed.

The next question relates to the type of tag we can put into the fish and how it can be found later. A tag, such as a small dart, can be put in the dorsal muscle of the fish and the time between the first and second capture will show the distance traveled, growth, and possibly conditions under which he is caught. I think we are all fairly familiar with the dart tag procedure, but the previous speaker, Mr. Squire, alluded to something which made me feel I should talk about a type of lure that is able to bring the fish to the boat without injury. Without any blood being shed, and without any interference with his swimming or breathing, the fish can be brought to the boat and kept almost stationary though you have to act quickly if you're going to tag and release the fish. A lure was developed here in Hawaii about 3 yr ago, and has been improved since then. The concept of taking a billfish with this lure is just the reverse of a normal lure in that this lure has no hooks at all. This new lure was developed with the idea that the billfish already provides the hooks on his bill. The bill in each billfish is covered with a lot of fine teeth and when proper material is applied to that bill you can hold him with the bill and bring him to the boat. As a matter of fact you hold him so well and can guide him to the boat much easier than if he is hooked in the mouth. You can use much lighter tackle to do it. I think that's what we're after.

I understand from a discussion last night with one knowledgeable person that probably it is not the hook or the dart tag which kills the fish or shortens his lifespan, but an accumulation of lactic acid from use of oxygen during the fight. I understand that oxygen is stored in the red muscle of the fish for an emergency. Then during the fight on rod and reel if he uses it all he is at the same point as the boxer when he is hanging on the ropes. Possibly this is what we have to avoid when we tag a fish, that is, we have to eliminate the fight on rod and reel. We go out purposely to tag a fish, possibly with a sonic transmitter in it, and then perhaps the fish will live no longer than 48 h. I believe when the last taggings were done here with sonic transmitter, the billfish did not survive long enough to get the information that was really wanted. We had a special boat down here with all the sonic gear and it seems a shame that these fish appeared to die so soon. I suggest that the new type of lure with a transmitter could be used to tag the fish without a fight; the leader would break after the fish had taken the lure and then the chase with the listening devices would go into effect.

Again I want to welcome you all to Kona on behalf of all the skippers, even those who aren't here this morning. I know they think sport fishing has developed to a very fine point, when these scientists will spend their time and their energy to come and hold a symposium on billfish. I think sometimes we underestimate the importance of the billfish here in Kona, and it was not until the international billfish tournament, originated by Peter Fithian, that we really started to make some strides and realize the importance of the billfish fishery. I take my hat off to Peter Fithian who has brought this to fruition.

D. Lewis

Thank you very much, George. The meeting is now open to questions from the floor.[6] Please identify yourself as this session is being recorded.

Discussion

Mr. Lewis:
In my privileged position as Chairman, I would like

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[6] For purposes of brevity, the question and answer section has been abbreviated and in some instances paraphrased. Also, questions relating to the mercury problem were similar to those raised during the special session on mercury; thus these have been omitted.

to ask the first question. Why do scientists have different length criteria for billfishes?[7]

Dr. Robins:

Generally billfishes from commercial catches or those found in the market places around the world have their bills cut off. If you are dependent upon a measurement that includes the bill then a great deal is lost unless adjustment factors can be used to determine a given length. Also, the bills in two groups of billfishes grow differently.

Captain George Parker (Kona) (comment):

For a long time there has been some confusion on what constituted a black marlin and how it differed from a blue or striped marlin. In a black marlin the fin is stiff from the outset and you cannot lay it back to the body without breaking the joint; this is not true of the other species.

Mr. Goadby (Australia) (comment):

The pectoral fin of small (less than 100 pounds) east Australian black marlin can be moved, though they will not lie back completely flat as do those of the blue and striped marlins. Therefore, we must use other identifying characteristics.

Mr. Palmer (Australia):

During a day's fishing a fisherman is likely to see a varying number of fish, sometimes surfacing, and sometimes encountering a strike then a miss. To what extent must the data be collected to be useful to the scientist?

Mr. Squire:

The amount of useful data collected depends on the circumstances and the fishery. We have obtained good data on catch per angler day by use of the card mail-in system. In some fisheries more detailed data are collected by the logbook method. What is needed is a standardized log which will ensure receipt of the kind of statistics needed for the sport fishery.

Dr. J. Delohery (Australia):

A question to Mr. Stroud. The Atlantic Ocean tuna agreement includes billfishes, while the Indo-Pacific and Pacific Ocean agreements do not. How can we get billfishes included into those two agreements?

Mr. Stroud:

You would have to amend the articles of the Convention. In case of the ICCAT, the term "and tuna-like fishes" was included and defined so as to specifically include the billfishes.

Mr. Shomura:

A clarification of a point raised by Mr. Delohery. I believe the Indo-Pacific agreement quoted by him relates to the Indo-Pacific Fisheries Council. This is only an advisory body and I believe does not currently have any management responsibilities.

Mr. Lester Walls (Oahu):

I would like to know if the silver marlin is a definite species or a juvenile fish.

Dr. Robins:

As far as we know in the Pacific Ocean we have a black marlin, a blue marlin, a striped marlin, a sailfish, and a shortbill spearfish. We have no evidence that there is any other kind of marlin-like fish in the Pacific Ocean. The fact that this "roundscale" spearfish or "hatchet" marlin has been uncovered in the Atlantic Ocean indicates that an eye needs to be kept open for things like this.

Mr. Frank Moss (Sport Fishing Annual):

Most fishing tournaments generally follow the IGFA rules. These rules are predicated on the use of hooks, so the question arises about IGFA acceptance of a hookless lure.

Mr. Elwood Harry (IGFA, Ft. Lauderdale, Fla.):

The IGFA through its international committee and clubs has overwhelmingly voted down the use of any entangling devices.

Mr. Frank Mather (USA):

Question to Peter Goadby. Is a billfish which "lights up" more apt to strike than one that does not?

Mr. Goadby (Australia):

It appears that fish "light up" more in warm water than they do in cool water. One angler reported that of 11 marlin he caught that had followed the bait, only 1 was seen to "light up." On the other hand in Cairns, black marlin are observed "lit up" from the time they are first sighted. It is my personal belief that the phenomenon is like birds exhibiting their brightest plumage during the mating season.

Mr. Eugene Nakamura (USA):

I would like to direct a question to some of the sports fishermen here. Fishermen in the Gulf of Mexico do not use artificial lures when fishing for billfish, but use fresh or frozen fish. Yet in this area (Hawaii) just about all lures are artificial. Why?

Captain Parker (USA):

This question comes up frequently on the charter boats. If we need live bait we catch them on the fishing grounds. Anglers are surprised that we troll for so long with artificial lures. We troll at high speeds in order to cover the maximum area. At these speeds it is difficult to maintain a frozen fish or even a freshly caught fish on the hook for any length of time. Also, we consider that the sound of the propeller and the boat's wake, the sound that the lure makes "diving" in the water, and the trail of air bubbles created by the lure, are all very important factors. In our experience, the artificial lure also has taken more of the large fish than the skipping bait or the live bait. Each area seems to have one favorite fishing method which is considered to catch the most fish.

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[7] During the course of the Symposium sportsmen and scientists commented on the need for a standardized set of measurements for billfishes. There was a consensus agreement that the publication by L. Rivas entitled "Definitions and methods of measuring and counting in the billfishes (Istiophoridae, Xiphiidae)" should be reproduced in this volume, since it is currently out of print. Rivas' paper appears as Annex 10.

Mr. R. Johnson (Sports Illustrated):
Question to Dr. Robins. Does the hookless lure extend the life of the fish after it has been released? This is apart from any questions of tournament rules.

Dr. Robins (USA):
I am not familiar with this particular lure. I am personally convinced that the reason a lot of fish, particularly blue and black marlins, die after release is the build up of lactic acid in the body after they have been "played" for a long time. To investigate this problem we need to use sonic lures and track the fish after release.

Mr. R. Johnson:
Does Captain Parker consider it possible to maintain a charter business with customers going out with the understanding that they are to use a hookless lure?

Captain Parker:
Yes. Trying to build a lure that will hold the fish on the end of the line has been the desire of man ever since fishing began. May I remind you of the advent of nylon lines, the glass fiber rod, and the two-hook lure.

Mr. Lewis:
As there appear to be no further questions, I will ask Peter Fithian to summarize this session.

Mr. Fithian:
Thank you, Mr. Chairman. Dr. Robins talked about the valuable information that could be derived from good photographs and how these should be taken to avoid distortion. An identification tag showing location and time of capture, and weight and length should be visible in the photograph. He said that scientists must follow up on what they request from the sport fishermen and I agree that this is a very important point.

Mr. Goadby spoke of the active manner in which Australian oceanic game fishermen have cooperated with marine scientists, especially in tagging programs. Results from these have already suggested some interesting migration patterns for the black marlin off the east coast of Australia.

Mr. Craig commented on the value of records and other data in fishing club files and how useful club yearbooks can be to the scientist. I know that Mr. Harry of the IGFA always asks clubs to send in their yearbooks and it occurs to me that this might be the simplest way for scientists to get hold of them.

Mr. Stroud spoke about the activities of the Sport Fishing Institute. In particular, he summarized the history of the conflicts between the Japanese commercial longline fishery for tunas and billfishes and the recreational fisheries in the Western Hemisphere, and how some of the problems were resolved. Finally, Mr. Stroud stated more funds were needed for game fish research and how this might be achieved.

Mr. Squire indicated the type of catch and effort data scientists need from the angler. He outlined the type of surveys he makes on an annual basis for the eastern Pacific Ocean area. He also emphasized the need to know how much effort (time) is deployed which results in no catch.

Captain Parker commented that he believed the charter boat captains and crew can provide a lot of good data for the scientists, both on the fish and the environment, if only they took the time to record it. He was also very concerned about the lack of revenue from the sale of the fish following the mercury problem, as this is a serious economic problem in the Hawaiian charter boat industry. There was a very interesting discussion of the hookless lure, which might be useful for tagging purposes as it causes no damage to the fish, apart from other conservation aspects.

The general discussion ranged widely, both on points raised by the panelists and from the floor. The most important related to requests for printed information on the correct way to measure billfishes and take photographs of them for scientific purposes; detailed standardized logs for sport fishing vessels; tagging methods; international fishery agreements and the billfishes; identification of rare species like the "hatchet" marlin or "roundscale" spearfish; and the "lighting up" of billfish at certain times. There was a long and lively discussion of the merits or otherwise of the hookless lure for angling and scientific purposes, and the official position of the IGFA with regard to this device from the sportsmanship standpoint.

Mr. Chairman, with your permission, I would like to advise this group of some resolutions which the Board of Governors of the HIBT intends to consider and present in a final form at a later date. The first, in draft form, is really addressed to NMFS, which has the authority and responsibility for matters dealing with marine sport fishing throughout the United States of America: "It has been established at the International Billfish Symposium that the successful work on billfishes to date has arisen as a by-product of other research, and whereas the billfish are generally conceded to be the ultimate fishing quarry though little is known about their biology and distribution, the Board of Governors of the HIBT resolves that the National Marine Fisheries Service be requested to focus attention on billfish research over the next 5-year period in order that a system for rational international management may be realized by a cooperative effort of all those parties involved."

The second will be a very self-serving resolution in which we suggest that the Secretary of Commerce consider appointing to the advisory committee of

NMFS a representative from the central Pacific Ocean area.

In relation to the mercury session, which we purposely put on in the evening and at which attendance was not as good as hoped, we are addressing a resolution to the Governor of Hawaii which discusses the problems, both economical and philosophical, brought about by State prohibition of the sale of marlin. The Governor is interested in what goes on around this coast; although he is not a fisherman, he is interested in this tournament and serves as Honorary Chairman. We will ask him to direct the appropriate department to undertake studies which may lead to an economic use of the carcasses and which might meet both the economical and philosophical requirements. There may be some additional things, Mr. Chairman, which we will put in the form of resolutions and present to the Board of HIBT at the appropriate time.

A final word, Mr. Chairman, to echo the words of Captain Parker this morning, to say what a pleasure it has been to the HIBT and myself to see you all gathered here in Hawaii.

Mr. Lewis:

Thank you, Peter. This concludes the proceedings here this morning. However, I do not think we should adjourn before I have had the opportunity to thank Richard Shomura for putting together this meeting. He did a lot of hard work with a fine result. Thank you very much. The meeting is adjourned.

Acknowledgment

The editors wish to extend their thanks and deepest appreciation to the many individuals who helped to put together this Symposium. Special thanks should be accorded Dr. Robert L. Edwards, who, as Associate Director for Resource Research, NMFS, Washington, D.C., provided initial guidance and support to this Symposium. Finally, the success of the Symposium could not have been achieved without the dedication and outstanding effort extended by Mr. Robert T. B. Iversen, Regional Representative in Hawaii for the Southwest Region, NMFS. Mr. Iversen was solely responsible for handling the many arrangements that needed to be done in Hawaii to prepare for the meeting.

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ANNEX 2

Welcoming Address
by
The Honorable Shunichi Kimura
Mayor, County of Hawaii

Thank you very much, Dick. This must be a very competent kind of gathering, because for once they got me a maile lei short enough to fit my stature.

But you know I'm particularly happy to have Mr. Roedel and Dick and all of you here at this very distinguished gathering of scientists and environmentalists and sportsmen. I do want to make a confession to all of you though, that the only knowledge that I have about fishing is that I do get seasick and by the food that I eat; I eat raw fish by the tons and I have a 10-gallon aquarium in my house and this is the extent of my abilities as far as the fisheries are concerned.

But I do want to, like all of the others, extend a very warm welcome to all of you on this Island; we're very privileged to have this kind of distinguished group of experts in the marine billfish area. However, I'm going to leave to Mr. Roedel the overview and the technical side because I know absolutely nothing about this area. But I do want to share with you some of the folks that the Island of Hawaii has in the areas of research and scientific endeavor.

I have a strong feeling that if this Island is going to depend upon agriculture and the visitor industry, I suspect many of us would be leaving this Island to live in San Francisco or La Jolla or some other swinging place throughout the country; what we really want on this Island is a combination. If we want agriculture, we want agriculture plus the expertise in tropical research in the agricultural area; if we have the visitor industry, we want the visitor industry not solely for itself but because we think that we can combine a very unique destination area. For instance, in this Kona area with Peter Fithian's imaginative leadership and the big-game fishing area, combined with the things such as Mr. Roedel and Dick and Bob are doing here on the Symposium I think creates a particularly unique and particularly exciting kind of a visitor destination area. And so we'd like to extend all of the best of resources that we have to develop that kind of scientific and research capability. As you know, NOAA already has a major facility up on Mauna Loa with the Atmospheric Research group. Up on Mauna Kea, the tallest mountain that we have, we also have the NASA people with their 85-inch telescope and the French coming in with their 150-inch telescope within a few years. In terms of geothermal kinds of research we obviously have a great expertise in volcanology; we'll try to extend this and participate with the Atomic Energy people and the people in the National Science Foundation and the other agencies so that we can have major research in the area of geothermal power and energy. We have approximately about one quarter million dollars in appropriations from the State and County governments for this particular kind of energy research. And if we look at the rains that fall on these Islands we have a fairly competent area in terms of cloud physics kinds of research at the University of Hawaii Hilo Campus. And we can go on and on. What we've done really is take all of the natural resources that are found on this Island and tried to develop them so that we can have fairly substantial research and development kinds of facilities on this Island. As I welcome you here I'd like to also ask your support, your help, and your counsel in how to develop the fisheries kind of expertise on this Island, in terms of developing facilities, in terms of inviting you people back again when you have additional information and additional need to get together. I've already asked Mr. Roedel for his assistance and he's already given me advice as to how we can go about it to try to extract field station and field facilities and possibilities of a common research station here on the corner area on the Island of Hawaii. We're pushing for a retreat, a scientific retreat area up on the northern part of this Island, so that we can have scientists come here to do research and, of course, to have a retreat in an area where they can quietly work on their cases and their particular kinds of endeavors.

So what we hope to do really on this Island, then, is to create a tremendous expertise in tropical agriculture, both in the business end and in the area of research. We also want to create a very unique visitor area, an area that's not only wonderful in terms of recreational visits, but also in this kind of a tremendous combination of the Peter Fithians and the National Marine Fisheries Service. Of course, we want to extend our research and development abilities throughout the Island of Hawaii and make these indeed one of four major industries. But in trying to achieve all of these very lofty and great expectations for this Island, we are going to need the help, the expertise, and the counsel of all of you. I hope that I can ask your help in trying to attract to these Islands various scientific conferences and symposiums and retreats because we do not have that much expertise or that much capacity in reaching all of the scientific and research groups that we need to come to this Island to hold their deliberations.

So again I want to thank you very much; we're very happy to have all of you here. It is a great privilege for all of us to have such a gathering of all of the experts in the areas of billfish and marine fisheries. I hope that if there is anything that we can do to make your stay here that much more pleasant or enjoyable please do not hesitate at anytime to call upon myself. Thank you very much.

ANNEX 3

Opening Address

by
Philip M. Roedel
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Mr. Chairman, Mayor Kimura, distinguished guests, participants in the First International Billfish Symposium. It is a great pleasure to be with you today, for the opening of what I am sure will be a most eventful Symposium.

I want first to bring you greetings from the Administrator of the National Oceanic and Atmospheric Administration, Dr. Robert M. White, who asked that I extend his best wishes to all of you.

This is a particularly happy occasion for me. I have many pleasant memories of Hawaii, extending back to the Pacific Tuna Biology Conference held in Honolulu in 1961 and including the Hawaii Governor's Conference on Central Pacific Fishery Resources in Hilo in 1966 in which, I recall, Mayor Kimura participated. There have been others as well, but these two meetings illustrate the importance attached to fishery resources both by officials of the State of Hawaii and by the Federal Government. The Symposium we are opening today is, I believe, a worthy successor to its forerunners.

This is the first scientific Symposium sponsored by the National Marine Fisheries Service since its founding nearly 2 yr ago. I think it is especially appropriate that the subject is a group of fishes of primary concern in the United States to sport fishermen. I say this because of the origin of NMFS, which was formed in 1970 as a component of the National Oceanic and Atmospheric Administration (pursuant to Reorganization Plan No. 4 of 1970, 84 Stat. 2090). The constituent parts of the new service came primarily from the former Bureau of Commercial Fisheries in the Department of the Interior. The service also includes, however, the migratory marine game fish program of the Bureau of Sport Fisheries and Wildlife, and this gives the new organization a far different role from that of its chief predecessor. The Symposium helps emphasize this: The concern of NMFS for the resource as a whole, and its responsibility to all user groups, be they sportsmen, commercial fishermen, or someone else.

The idea of an International Billfish Symposium actually dates back to the late 1960's when Richard Shomura was stationed at our Honolulu Laboratory. He maintained his interest when he transferred to the mainland in 1970, and he organized a workshop on billfishes which was held at the Tiburon (California) Fisheries Laboratory in 1971. Final plans for the Symposium were developed at that workshop.

The Symposium agenda is comprehensive and substantive, and I want to congratulate Mr. Shomura, who served as Chairman of the Organization Committee, and the other committee members, Messrs. Iversen, Squire, and Williams, for a job well done.

I want at the same time to express my appreciation to the cosponsors (the County of Hawaii, the Hawaiian International Billfish Tournament, and the State of Hawaii) for all they have done to make this event possible, and to the Food and Agriculture Organization of the United Nations for its support.

Why a symposium? There are two primary reasons. First, billfish research in most parts of the world is a by-product of other activities primarily in areas where there is an active tuna research program. Scientific study of the billfishes has thus been relatively limited. Most of what we know about the size and distribution of stocks, and effects of fishing upon them must be inferred from catch statistics from the fishing nations, primarily Japan.

Because of this generally secondary role, communication among scientists on a worldwide basis has been something less than adequate. This Symposium is a step in the right direction toward meeting what we regard as an urgent need for scientists to exchange ideas and viewpoints. Second, and of equal importance, the Symposium will permit interaction, also on a worldwide basis, between scientists and sport fishermen with respect to a major high-seas fishery, something that appears to be both unique and long overdue.

Let me turn now to the fishery. While man has harvested billfish since before recorded history and has taken them recreationally for many decades, the total catch has been relatively small until fairly recently.

We have, since World War II, seen a marked expansion of longline fishing for hitherto relatively unexploited high-seas stocks. Before that time, billfish had been harvested lightly, primarily because they are nonschooling species scattered over wide areas, and hence were not taken efficiently before the advent of longline gear.

The most recent statistics published by the Food and Agriculture Organization of the United Nations show that the global commercial catch in 1970 was about 101 thousand metric tons (Table 1). Of this, about 70 thousand were taken in the Pacific Ocean, 20 thousand in the Atlantic Ocean, and 10 thousand in the Indian Ocean. While some 20 nations reported billfish catches in 1970, Japan continued to dominate with some two-thirds (67 thousand metric tons) of the total. Taiwan ranked second, with over 15 thousand. Canada, in third place, took under 5 thousand. The United States was eighth, with about 700 metric tons. The U.S. commercial fishery is relatively insignificant; it is sport fishing that is the critical item in this country. The total sport fishing catch is unknown, but it unquestionably adds considerably to the total harvest.

Sport fishing for billfishes takes place in many parts of the world: East Africa, Australia, American Samoa, Hawaii, California, the Pacific Ocean waters of Mexico, the Gulf of Mexico, and several areas in the Atlantic Ocean. Commercial fishing is even more widespread but it is basically a high-seas fishery. The sportsmen generally operate much closer to shore. This is not to say there is not or has not been conflict for there has, particularly off the west coast of Mexico and in the Gulf of Mexico, where the longline fishery did intrude into some prime big-game fishing grounds. The big-game anglers watched this incursion and noted the reports of increased catches of billfishes. They understandably became alarmed for the future of their sport, and indeed for the future of the resource itself.

What about economics? Hawaii offers a good example of the relative magnitude of sport versus commercial fishing for billfishes in the United States. In 1968 some 35 charter boats earned an estimated $700,000 in charter fees. The commercial value of billfishes landed by the small longline fleet operating in Hawaii that year was about $225,000. In 1970, the value of commercial landings of billfishes was about $290,000, but in 1971 it fell to less than $150,000. In 1971, the charter boats numbered about 48, and the earnings from sport fishing for billfishes were about $1.3 million. Obviously in Hawaii, revenue from recreational fishing for billfishes far exceeds the economic gains from conventional commercial fishing enterprises. Similar circumstances likely prevail elsewhere. (The marinas and vessels supporting a charter fishery are also commercial enterprises, but they are not identified as commercial *fishing* enterprises in the usual sense of that term.)

We are thus dealing with a group of oceanic fishes prized equally by sportsmen and by commercial fishermen. They comprise a resource of unknown size, but the rapid growth of the global fishery in itself is enough to give us cause for concern. Through this Symposium, we hope to get a better fix on the present state of knowledge and where we should devote our major efforts in the next few years, if we are to understand the dynamics of these several species.

Assuming we have or can soon attain sufficient knowledge of the status of the stocks to permit rational recommendations for management, what then? If analyses of available data indicate a need for reduction in fishing effort on some or all of the stocks, how does one proceed? We are faced with the need to understand some extremely complex biological systems, and with the equally difficult matter of solving political and social problems of allocation among nations and among user groups within nations. Except in the Atlantic Ocean, where billfishes are included in the frame of reference of the International Commission for the Conservation of Atlantic Tunas (ICCAT), no mechanism for international action exists.

There is, of course, a Law of the Sea Conference (LOS) scheduled for Geneva in 1973. A number of preliminary meetings have been held, and as a matter of fact, a preparatory meeting is now taking place there with strong representation by knowledgeable fisheries people. On the U.S. side, industry

Table 1.—World catch of billfishes by waters, 1970.

Species	Pacific	Atlantic	Indian Ocean	Total
	Thousands of Metric Tons			
Sailfish	9.1	1.0	1.1	11.2
Blue marlin Black marlin	18.8	3.0	4.1	25.9
Striped marlin	22.1	0	3.1	25.2
White marlin	0	1.0	0	1.0
Broadbill swordfish	20.4	15.7	2.2	38.3
Total	70.4	20.7	10.5	101.6

Source: FAO Fisheries Yearbook 1970

(not sportsmen) has had considerable input into the preparatory meetings, and NOAA and NMFS have had top level people on the U.S. Delegation.

The present U.S. position on fisheries was articulated most forcefully by Ambassador Donald L. McKernan at last spring's preparatory meeting held at the United Nations in New York.

To quote Mr. McKernan, this position is " . . . based on a species approach, that is, on the principle that the management and harvesting of fisheries should be governed by the biological distribution and migration of fish stocks, rather than by arbitrary jurisdictional boundaries." The position thus depends on the fact that some species are distributed along coastlines, others are principally migratory on the high seas, while still others are spawned in freshwater and migrate to the coastal areas and onto the high seas. These three categories of coastal, high seas, and anadromous stocks form the basis for the species approach to international management.

Marine species in general and billfishes and tunas in particular do not respect the lines drawn in the ocean by governments about their coastlines to delineate their territorial seas or contiguous fishing zones. This is one of the reasons fisheries is probably the thorniest of all the LOS issues.

The United States species approach calls for the coastal fishes, such as anchovies, cod, and hake, to be managed by the adjoining country, with that country having a preference in harvesting those stocks. If the adjoining country did not catch all the harvestable surplus of a given stock, other countries could take the remainder. The anadromous species, such as salmon, would be managed throughout their migratory range by the coastal country.

The high-seas species, such as tunas and billfishes, would be managed through an international arrangement, either of a regional or worldwide nature, perhaps similar to or based upon existing international conventions for conservation and management of high-seas resources. Existing conventions of this nature include the very successful Inter-American Tropical Tuna Commission in the eastern Pacific Ocean, and the more recently established ICCAT (which includes billfishes and to which I have already alluded).

The whole question of how best to manage high-seas stocks thus remains unresolved, and we cannot hope for resolution until we know the outcome of Geneva. We can hope that a rational scheme will be forthcoming and that by the time it is effective we will be well on the road toward obtaining the scientific knowledge basic to its implementation.

I want to turn briefly to a serious problem facing us particularly in the United States. I refer to heavy metals found in small amounts in many fishes, and for one of which, mercury, the U.S. Food and Drug Administration (FDA) has established a guideline of 0.5 parts per million. Certain fish, among them billfish and particularly swordfish, frequently exceed this tolerance. Hawaii offers a good example of the impact of mercury on fishing.

Until the heavy metal problem arose in 1970, Hawaii had no difficulty in disposing of the billfish sport catch, for the fish were used as food ashore. Mercury at levels above the FDA guidelines changed this, and both sport and commercial fishermen are now faced with determining how to dispose of the catch.

Because of the intense local and worldwide interest in the subject, the scientific papers bearing on it will be summarized at a special public evening session at which Dr. Albert C. Kolbye, Deputy Director, Bureau of Foods, U.S. Food and Drug Administration, will speak.

While this is the first time a scientific meeting has been held in concert with the Hawaiian International Billfish Tournament, it is the 14th year for the tournament. Mr. Peter Fithian, its chairman and a participant in the Symposium, is one of the founders of the tournament which has done so much to further sport fishing in Hawaii.

Tournaments of this sort are becoming even more popular and more numerous. On the Pacific coast, we have the San Diego Marlin Club Invitational Light Tackle Tournament. A swordfish tournament will be held for the first time this September near Santa Barbara, Calif. Several southern California billfish clubs stage tournaments about the tip of Baja California, which with the west coast of Mexico from Acapulco to Guaymas, has long been an internationally famous billfish area. One of the pioneer tournaments is that conducted by the Tuna Club of Avalon, the world's oldest billfishing club. It was founded in 1898 by Dr. Charles F. Holder, the originator of the Tournament of Roses in Pasadena, Calif. The organization began as a bluefin tuna club and held its first tournament in 1899. It expanded to include striped marlin in 1903, and recorded its first swordfish on rod and reel in 1913.

All along the Atlantic and Gulf coasts, major billfish tournaments are held annually: from Nantucket and Cuttyhunk, Mass.; Cape May, N.J.; Hatteras, N.C.; Cape Canaveral, Palm Beach, Miami, and Panama City, Fla.; New Orleans, La.; Galveston, Tex.; San Juan, P.R.; and the islands of Cozumel and Mujeres off Yucatan, Mexico. This does not pretend to be a complete list, but it does show the widespread popularity of these tournaments.

No such recitation would be complete without mention of the International Game Fish Association (IGFA), founded over 20 yr ago by Mr. Michael Lerner, who is today its chairman. One of the objectives of this organization is to keep world records of saltwater game fish. The IGFA has as members the competitive clubs around the world and is governed by an international committee. Its contributions to marine game fishing are legendary.

I want to touch on cooperative research efforts. We have for several years been conducting a cooperative tagging project off the west coast of Mexico in an effort to monitor the impact of fishing, including the Japanese longline fishery, on billfish stocks. We have expanded our studies this year to utilize the catches made during tournaments to give us additional information on stock and recruitment in the South Atlantic Ocean and Gulf of Mexico. The cooperative game fish tagging program that Mr. Frank Mather of the Woods Hole Oceanographic Institute has fathered for more than 20 yr, will be supported substantially by NMFS as a part of our expanded game fish program. Information to be gained from these studies is vital to our mission of representing all U.S. fishery interests, sport and commercial, in negotiations with other high-seas fishing nations.

In closing, I want to propose that this Symposium be dedicated to the memory of two men, one a scientist, one a sportsman, who did much to further our knowledge of the ocean and of fisheries: Dr. O. E. Sette and Col. John K. Howard.

Mr. Chairman, Mayor Kimura, I believe we are opening a Symposium that will have a lasting value. I appreciate the opportunity to be a participant.

Aloha and mahalo.

ANNEX 4

Address
by
Michio Takata
Director, Division of Fish and Game

Mr. Chairman, it is certainly a pleasure to see such an array of scientists and sportsmen from all corners of the earth assembled here for this Symposium. I would like to merely add our welcome to that extended by Tom Stuart, on behalf of the Division of Fish and Game of the Department of Natural Resources. I extend my warm welcome and aloha to you all and although we are cosponsors of this Symposium, I must admit that the National Marine Fisheries Service did most of the hard work that went into organizing the Symposium. The National Marine Fisheries Service has put together a fine looking program and I look forward with you to a very interesting and productive 3 days of discussion and exchange of ideas and information about the billfishes. I wish you all a very pleasant visit. Mahalo.

ANNEX 5

Address
by
J. Thomas Stuart III
Special Assistant to the Marine Affairs Coordinator
State of Hawaii

I am happy to be representing Dr. John Craven and the Office of the Marine Affairs Coordinator here today.

Increasingly we are aware of the importance of oceanic studies in the future of all nations, but especially those that border the great oceans of our planet.

This week's Symposium is a strong reflection of Hawaii's deepening involvement in our total understanding of one of man's least understood frontiers.

Hopefully, the future will see many more such gatherings as today's. For no matter how specific the subject area, all new findings will benefit more than a few in our continuing quest to find the solutions to problems of pollution, new food resources, better use of *all* marine resources—not least of all the more effective and pleasurable use of our leisure time.

Thank you.

ANNEX 6

Address
by
Peter Fithian, Chairman
Board of Governors, Hawaiian International
Billfish Tournament

Aloha. I cannot tell you how delighted the billfish tournament is that you are all here. I do not think that you should all stay in one room at one time because if anything happened I do not know who else would be working on the billfishes. Believe me this is very important to a lot of sportmen like myself. I am sure in this room on Saturday morning that you will get many questions and ask many questions that could throw a lot of light on a lot of subjects which I am sure are near and dear to your hearts and ours. I sincerely hope that as a result of the meetings here between scientists and sportsmen, we will be able to provide all the channels of communication which I think have been sorely lacking in this field. I have no background in science at all. I managed normally to flunk chemistry and physics annually for a number of years, but I do have some feel of how sport fisheries are organized in this part of the world. I am delighted that so many of you have come to Kona. I extend you a warm welcome to come to the pier, wearing your badge please, as it gets a little hectic down there. If there are things you want to do with the fish, please let us know so that we can make arrangements. After all we are told you do not get them every day in your laboratory. We had nine marlin as of noon today, so that means possibly we will have another half dozen before the afternoon is over. Enjoy yourself, this is one of the great fishing areas in the world and one of the very pleasantest places to be located. Aloha.

ANNEX 7

Text of Cable
from
F. E. Popper, Assistant Director-General
Department of Fisheries
Food and Agriculture Organization
of the United Nations
Rome, Italy

"FAO extends best wishes for successful symposium which will contribute greatly to improve knowledge on billfish biology and resources signed Popper Assistant Director-General (Fisheries)."

ANNEX 8

Potential Health Hazards of Mercury in Fish

by
Albert C. Kolbye
Deputy Director, Bureau of Foods
and
Acting Director, Office of Science,
Food and Drug Administration
Washington, DC

At the outset, I should like to emphasize several points that I would like you to keep in mind throughout my presentation. I will be talking initially about the effects on health caused by *excessive* exposures to methylmercury. In the normal course of events there is very little, if any, likelihood that people living in the United States would receive exposures comparable to the Japanese villagers later described. However, it is necessary to describe what can occur in the extreme if we are to understand the present perspective on mercury as a potential health problem in the United States and why the FDA has set a guideline for mercury in fish.

There is no reason for public alarm or distortion of risk by magnification beyond the true perspective, because no health crisis is imminent from mercury in fish. We should understand, however, that there is reason to exercise prudence and caution, hence the existence of the FDA guideline. Towards the end of my talk I will go into the guideline itself and explain some of the reasoning behind it. I would also like to emphasize that there has been no fully documented instance of a U.S. resident suffering clinically evident mercury poisoning from exposures to mercury in fish. However, the occasional presence of subclinical brain damage from *excessive* exposures to mercury in fish has not been excluded, particularly in relation to children of mothers who eat *unusually high* amounts of fish containing *substantial* amounts of mercury in the form of methylmercury. One reason for the guideline is to protect pregnant women from inadvertently damaging their unborn children.

The potential health hazards of *excessive* exposures to mercury in fish primarily relate to the particularly toxic form of mercury most frequently encountered in both freshwater and pelagic fish. Methylmercury is the particularly toxic organic form which, because of its biochemical characteristics, is almost totally absorbed from the human gastrointestinal tract and circulated through the blood to the various organs and tissues where a range of harmful effects can potentially occur. In contradistinction to either inorganic or other organic forms of mercury when ingested, methylmercury can more readily penetrate the "blood-brain barrier," enter the brain tissue, and cause irreversible damage to brain cells. If methylmercury were easily and quickly excreted from the human body, then occasional exposures to foods containing higher than normal background levels of methylmercury would present little reason for public health concern. However, such is not the case with methylmercury.

When we speak of the biological half-life of a substance, we refer to that period of time necessary before the body can rid itself of 50% of the initial amount present. The biological half-life of methylmercury in humans has been determined by observational studies on exposed humans and by direct experimentation on human volunteers with orally administered radioactively labeled methylmercury. The observational results indicate that 69-70 days and 76-83 days represent the biological half-life for red blood cells and plasma, respectively, after ingestion of fish contaminated with methylmercury. The biological half-life of methylmercury-203 as determined by total body measurement of the volunteers was 70-74 days.

Why should we be concerned with this biological half-life of 70 days? The practical significance relates to the problem of accumulation in the body if intake exposures are significantly greater than excretion. Please note that various organs such as brain tissue may have a longer half-life than 70 days, while other tissues may have a shorter half-life, thus resulting in the average net half-life of 70 days. Our primary concern is with accumulation of methylmercury in the brain and at this point I should stress not only the adult human brain but more importantly the developing fetal brain. Methylmercury easily crosses the human placenta into the blood of the human embryo as it develops in utero. As the human embryo goes through the various stages of development before birth of the infant, its developing tissues are much more sensitive to damage from toxic substances than are adults. This is especially true for fetal brain tissue which can be exquisitely sensitive by comparison.

Accumulation of methylmercury in the human body has been documented many times as to the occurrence of the phenomenon and the brain damage it has caused in humans unfortunately exposed to highly contaminated foods. Additionally, we have other information from accidents and industrial exposures of pesticide workers. The results of experimental exposures of test animals, including monkeys, corroborate the cause-effect relationships of methylmercury to brain damage in human adults and infants. I will try to summarize the most significant points of information for you.

Two episodes occurred in Japan involving fairly large numbers of people and the opportunity to perform in-depth studies. The villages of Minimata and Niigata suffered similar problems during the 1950's and early 1960's. Fish and shellfish in the areas contained high levels of mercury (almost entirely in the form of methylmercury) resulting from local pollution by industrial sources. As you know, the Japanese consume more seafood in their average diet than we do. There were 121 cases of human methylmercury poisoning reported in Minimata of whom 46 died. Among the 121 patients, there were 23 infants and children who were affected with a severe cerebral palsy-like disease from 1954 to 1959. The important thing to remember here is that none of these infants and children so affected had consumed any of the contaminated seafood themselves. Most were born with the affliction not only being clinically obvious but in many cases, severe. Some of the severely afflicted have never seen, heard, spoken, or made a purposeful motion in their lives and in the figurative sense they exist as human vegetables. Others are less affected but still severely handicapped. Now comes the "hooker"—their mothers appeared to be normal. There were no clinically obvious signs of poisoning among the mothers at that time, yet their bodies had acted to accumulate methylmercury which was transferred through the placenta to their own children while the children were developing embryos in the womb.

An additional 47 people, 6 of whom died, were reported from the Niigata episode. I visited Japan in 1971 to perform a follow-up evaluation on the Minimata villagers and learned that more cases have been recognized than had been reported earlier, apparently due to the delayed effects of methylmercury poisoning not being recognized earlier in some of these patients. One case was of particular interest. It involved a physician who obviously would be more likely to recognize the early symptoms of mercury poisoning which include tremor, nervousness, and impairment of both vision and coordination. He celebrated one evening and drank too much. Instead of waking up with a hangover, he awoke the next morning with clinically obvious symptoms of mercury poisoning and died 10 days later from the disease. At autopsy, his brain showed advanced tissue damage with all the typical brain tissue pathologic findings of mercury poisoning. Apparently, he had been able to compensate partially for the damage in brain function. Since the onset of the disease in adults can be gradual he was able to compensate enough to live a fairly normal life until additional brain damage from high alcohol consumption tilted the delicate balance of compensation and his brain could no longer function well enough.

Similar advanced brain damage has been noted to result in Scandinavia after accidental short-term industrial exposure to alkyl mercuric pesticides in which the worker involved died 20 yr later from an unrelated cause without additional mercury exposures. There have been other unfortunate human experiences with methylmercury poisoning dating as far back as the original laboratory workers who first synthesized the compound and as recently as the current massive poisoning outbreak in Iraq due to the wrongful diversion of methylmercury treated seed wheat by farmers into bread.

The ability to compensate partially for damaged brain tissue has also been noted in Swedish studies of monkeys experimentally exposed to methylmercury. Some of the monkeys apparently were largely unaffected as far as their normal patterns of brain function were concerned, while others showed gross deterioration of brain function much earlier during the course of the experiment even though the exposures to doses of methylmercury were similar. Generally speaking, however, once a monkey showed signs of brain damage, further deterioration was very rapid with death usually following shortly. When some monkeys showed signs of advanced damage, the Swedish investigators then sacrificed several other monkeys apparently unaffected by similar exposures to methylmercury and found extensive brain damage at autopsy. Also, when monkeys apparently unaffected were allowed to live longer, symptoms then occurred with unpredictable sudden rapidity and a quick demise. Similar findings have been noted when cats and rats were studied. These were all adult animals.

There are several points that these findings bring to our attention. Severe brain damage from excessive exposures to methylmercury may go undetected in some adults for a while but the damage has occurred even though the time of onset of clinically obvious symptoms may vary with the particular individual. The brain damage is irreversible although partial compensation may temporarily delay onset of obvious disease. Excessive exposure to methylmercury may also contribute to early demise of brain function without being recognized unless specific examinations are performed by pathologists. Excessive exposures to other toxic substances that can damage brain tissue can produce interactive effects and potentially reduce the ability of the human body to tolerate subclinical exposures to methylmercury.

Also of interest in Minimata was the observation by public health officials that a number of teenage children in the village who were born around the time of the original episode are now experiencing difficulty in coordination when they attempt to play baseball and basketball. Others have visual impairment and more obvious signs. It would appear that subclinical brain damage had occurred earlier in their lives, probably before they were born, but signs of brain damage were delayed and are now beginning to be seen.

In Niigata, the lowest blood methylmercury level associated with toxic symptoms was 0.2 ppm. This level has been exceeded by certain Swedish fishermen eating freshwater pike from streams contaminated by mercury effluents from pulp-paper operations. So far, they have not shown any obvious symptoms but further investigation is indicated and we hope autopsies are obtainable in the future.

However, the blood level at 0.2 ppm mercury has been made the reference point that both Swedish and American health authorities use as the threshold of toxicity. Using the biologic half-life data to perform steady-state calculations, it has been determined that a daily intake not to exceed 0.3 mg would permit a 70-kg (150-pound) individual to remain at or below a blood level of 0.2 ppm. Both the Swedes and the Americans determined that a 10-fold safety factor was necessary and appropriate to protect individuals with unusual susceptibilities and infants from subclinic brain damage.

Accordingly, to maintain blood methylmercury levels at or below 0.02 ppm, average total dietary intake of methylmercury should not exceed 30μ g per day. This permits an individual to eat 60 g of fish at maximum permissible mercury levels (approximately 0.5 ppm) each day over a long period of time, without invading the safety factor and accumulating methylmercury in the body such that blood levels would exceed 0.02 ppm. We know that Americans eat less fish than do the Japanese, consequently since the average serving of fish in America approximates 210 g, which is a little less than ½ pound, this means that two meals of fish at guideline would use up 1 week's "ration" of methylmercury (additional exposure to inorganic mercury). Or said another way, one meal of swordfish with average mercury content at 1 ppm uses up a week's ration of methylmercury. Fortunately, most fish from both fresh and salt waters are well below guideline. Since many people who eat fish eat several meals per week, especially "weight-watching" women during their child-bearing years, the FDA guideline exists to protect people who like to eat fish from the potential hazards of accumulating *excessive* methylmercury in their bodies, and especially to protect children from in utero exposures to methylmercury that could cause clinical or subclinical brain damage.

ANNEX 9

Status of Mercury Studies in Hawaii

by
Richard A. Marland
Interim Director
Office of Environmental Quality Control

The State of Hawaii became concerned with the methylmercury in fish products in the month of April last year. By May of last year we had conducted sufficient analyses under the auspices of the State Department of Health to show that the average total mercury content of marlin entering the market in Hawaii was just over 4 ppm. These results were corroborated by the laboratory which Ms. Shultz represents here, the Pesticide Study Laboratory. At that point we asked the fishing industry of Hawaii to withhold sale of the blue marlin on a voluntary basis. This has been done ever since the request was made. It was only fair that having had this kind of cooperation from the fishing industry, the State of Hawaii should exert all possible efforts to establish whether removal of this species from the market was justified or to establish the conditions under which it could be sold. The Pesticide Laboratory of the University has been conducting analyses to determine the extent to which methylmercury is present as part of the total mercury value. There are two other efforts now going on, sponsored by the State. One of them is of such size and importance that we have requested funding from the National Science Foundation. We have not yet had an affirmative response, but this would be a 3-yr study at a cost of over $500,000. It will include the evaluation of some 9,000 people in Hawaii who are known to have a fish-eating habit. You've heard Dr. Kolbye point out that one serving of fish on the order of 7 ounces per week at 1 ppm gives you a full week's quota of methylmercury. If you're talking about a fish of 4 ppm, you get down to something under 2 ounces a week. It is not unusual for people of Japanese ancestry in Hawaii to eat a third of a kilogram of fish a day. On this basis it becomes very important that the fish being consumed to that extent does indeed contain the lowest possible levels of organic mercury. So the study of these 9,000 people of Japanese ancestry would be conducted as an historical study to determine if there is any evidence in their medical history of an effect of mercury poisoning. There would also be another study of some 300 people of Japanese ancestry. This 3-yr study will involve a very careful monitoring of the diet of these people, examination of their medical history, and observations made by physicians. The participants would all be residents of Lanai; they are already being studied for medical deficiencies. This study, which is an extensive study planned for 3 years' duration, has not yet been started because the cost of the project cannot be met at the local level.

Recognizing that we might not be able to get a human epidemiological study mounted immediately, the University of Hawaii, Department of Animal Sciences, started a program of research in the winter in which they used swine as an experimental animal. Swine, in this case, is an excellent animal because the metabolic system of swine is almost identical to that of human beings. There are some preliminary data available now from this swine-feeding experiment. Substantially there were five groups of swine, one on a control ration of feed, another on normal feed plus 1 pound of raw fish a day, and three experimental groups in which this 1 pound of fish had added mercury of 0.5 ppm, 5.0 ppm, or 50 ppm. These pigs were again subdivided because of the interesting results coming from Ms. Shultz's work so that we had half of them on organic mercury and half of them on inorganic mercury. Not too surprisingly, of those pigs that were receiving 50 ppm of organic mercury, or methylmercury, none lived past 26 days. They were the only pigs on trial that died during the experiment. Pigs that were fed 50 ppm of inorganic mercury showed liver damage and lymph node damage, and as yet we have not conducted the pathological examination of these tissues so we do not know if there was further damage. Pigs that were fed 5 ppm of organic mercury in marlin appeared perfectly normal. Upon slaughter, hemorrhage on the periphery of the lymph nodes was noted, the lymph nodes were enlarged, and the livers had developed fatty tissue above them. There seemed, therefore, to be some gross pathology in the pigs that were fed marlin with 5 ppm of organic mercury. Pigs fed 5 ppm of inorganic mercury showed no symptoms or any type of pathology other than perfectly normal growth. Those that were fed the lowest level were perfectly normal, even in the case of 0.5 ppm organic mercury. The reason for selecting these levels, of course, is to establish, as Dr. Kolbye has pointed out, the validity of a 10-fold safety factor. Dr. Kolbye will be pleased to hear that from each of these trials two of the females are being retained for breeding purposes and they will be studied for three generations to see whether or not there is a placental transfer of mercury to the offspring. These experiments, we hope, will lead to some type of recognition of the hazard of mercury. We hope the human epidemiology experiment will lead to some type of recognition of the risk, these data again to form a base upon which decisions can be made. We wish that we could say at this time that the data are sufficient to make decisions; they are not. We don't know whether there will be sufficient data. We hope, of course, it will be soon.

ANNEX 10

Definitions and Methods of Measuring and Counting in the Billfishes (Istiophoridae, Xiphiidae)[1],[2]

by

Luis Rene Rivas

Abstract

The need for definition and standardization of methods of measuring and counting in ichthyology is discussed, with special reference to billfishes. A series of measurements and counts for the latter group is proposed and methods and definitions for each are given. The body length is discussed in more detail in connection with its importance as a base length and attention is called to the need for dissection in order to ascertain accurately the number of spines in the first dorsal and first anal fins.

Introduction

The need for accurate definition and standardization in the use of biometric and meristic characters in systematic ichthyology has long been recognized (Ricker and Merriman, 1945). It is obvious that with the exception of truly self-explanatory characters, most measurements and counts must be defined in order to enable other workers to interpret the data. The need for standardization arises from the fact that in most cases, different methods (as applied to a given group), no matter how well defined, cannot be equalized for comparative purposes.

Owing to the high precision required, lack of definition and standardization of methods becomes quite a problem in the study of closely related species or infraspecific categories, and especially in the biometric analysis of populations where several independent workers using different methods may be working on the same group. Furthermore, the marked differences in structure existing among certain families of fishes usually prevent the application of a method to groups other than the one for which it was designed.

In recent years, the increasing interest in the biometric analysis of populations of tunas by various independent workers, has brought about the necessity to define and standardize the methods used in measuring and counting. The various methods which have been proposed are essentially in agreement (Godsil and Byers, 1944:125-129; Marr and Schaefer, 1949; Rivas, 1955) and have been successfully adopted by practically all workers in the field.

Also recently, new interest has developed in the taxonomy and population analysis of the sailfishes, spearfishes, marlins (Istiophoridae) and broadbill swordfish (Xiphiidae), a most confused group collectively known as "billfishes."

As far as can be ascertained, no formal methods of measuring and counting have ever been proposed for the billfishes. A survey of the literature shows that most of the methods used vary among the different workers and that lack of definitions renders the measurements and counts difficult or impossible to interpret. In addition, certain methods of measuring and counting employed in the past appear to be unsatisfactory and have resulted in questionable taxonomic interpretations.

For reasons already indicated above, the methods employed in the tunas cannot be applied to the billfishes. It is the purpose of the present paper to propose a series of measurements and counts for the latter group, based on previous field and laboratory experience as a result of studies conducted under sponsorship of the Charles F. Johnson Foundation. New characters not previously used in connection with billfishes are also included.

All the measurements described (excepting body girth) are straight-line distances and are made in metric units to the nearest millimeter, with slide calipers or dividers according to the size of the fish and the distance to be measured. (See also Godsil and Byers, 1944:125, and Marr and Schaefer, 1949:241, 242). In large fish, long measurements beyond the range encompassed by the larger calipers may be made with a steel tape graduated in metric units. For this purpose sliding metal or wooden arms similar to those used in the calipers should be attached to the tape, taking care that the tape remains straight during the measurement, with the arms perpendicular to it. As already pointed out by Morrow (1952:53, 54), measurements taken with a tape alone are not satisfactory, since a straight line distance can seldom be obtained.

Also, in order to avoid error in the longitudinal measurements, the axis of the body should be maintained as straight as possible. This may be accomplished by placing the specimen on a flat surface and properly propping up the head, the caudal peduncle and the caudal fin. Although it is conventional in ichthyology to use the left side of the fish for the lateral measurements, the best, or either side should be selected, according to the condition of the part to be measured. The jaws should be tied closed, especially in connection with measurements involving the tip of the mandible as a point of reference.

The numbers in the text for each measurement correspond to the numbers in the figure.

Measurements

1.—*Body length.*—A survey of the literature shows a great deal of inconsistency as to the selection of a body length in billfishes and lack of definition whereby the points of reference of this measurement can be accurately established. With very few exceptions, the instrument employed is not mentioned and there is no statement as to whether or not the measurement follows the curvature of the body (tape) or constitutes a straight-line distance (calipers or dividers).

It must be emphasized that since most, or all, other (relative) body measurements are referred to the body length as a base length, regardless of the method used in expressing proportions (ratios, regressions, etc.), this character must be defined with great care. It is obvious that if the base length is in error, all body proportions will also be in error regardless of how accurately the body parts may have been measured.

The "standard length" or "body length" for billfishes as used by most workers in the past does not seem to be satisfactory for various reasons. There has been agreement in the selection of the anterior end-point (tip of bill) but the posterior end point is variously interpreted as " . . . tail base" or " . . . mid-point of the peduncle . . ." (Conrad and LaMonte, 1937, table 1 and p. 209); or " . . . the midpoint of the shallowest vertical diameter of the caudal peduncle," (Gregory and Conrad, 1939:444), etc. Other workers offer no definitions or simply refer to "standard length" (deBuen, 1950:171) without further comment.

Despite lack of absolute standardization (Ricker and Merriman, 1945), most ichthyologists agree in that "standard length" is the straight line measurement taken between the tip of the snout and the middle of the caudal base, where the middle caudal ray joins the last (hypural) vertebra. In the billfishes, however, the middle of the caudal base cannot be determined without involved dissection, and the structure of the hypural vertebra and the caudal fin do not permit the determination of an accurate point of reference. Even after performing dissection, the point cannot be estimated from external form. For obvious reasons, the middle point on the posterior margin of the middle caudal rays (crotch of tail) constitutes a much better point of reference from the point of view of accuracy and convenience. In addition, the median caudal rays in billfishes are well protected by the upper and lower lobes of the fin, and are very seldom damaged.

As to the anterior point of reference, the tip, or a considerable portion of the distal end of the bill is frequently broken off, or the bill itself may be malformed and not attain its true length. For this reason, many otherwise valuable specimens have to be discarded or an inaccurate body length will result if the tip of the bill is used for the anterior point of reference. The mandible, on the other hand, is well protected by the bill and its tip is very seldom broken off or malformed.

In the light of the above discussion, it is therefore proposed that the body length in billfishes be measured between the tip of the mandible (with the jaws closed) and the middle point on the posterior margin of the middle caudal rays.

2.—*Body girth.*—Measured with a tape on one side of the body following its curvature from the uppermost point on the edge of the dorsal groove, vertically to the edge of the pelvic groove (midline of belly in the swordfish); the resulting figure is then multiplied by two. This character, when expressed as a proportion of the base length, serves as a good indicator of the degree of robustness of the body.

3.—*First predorsal length.*—Measured from the tip of the mandible to the origin of the first dorsal fin. The latter point is the intersection of the anterior margin of the fin with the contour of the back when the fin is held erect.

4.—*Second predorsal length.*—Measured from the tip of the mandible to the origin (as defined above) of the second dorsal fin. The origin of the second dorsal is not as clearly defined as that of the first, and the point must be estimated as accurately as possible. Since this is a long measurement, the error, if any, is negligible.

5.—*Prepectoral length.*—Measured from the tip of the mandible to the origin of the pectoral fin. The origin of the pectoral fin is the intersection of its anterior basal margin with the side of the body, when the fin is held erect.

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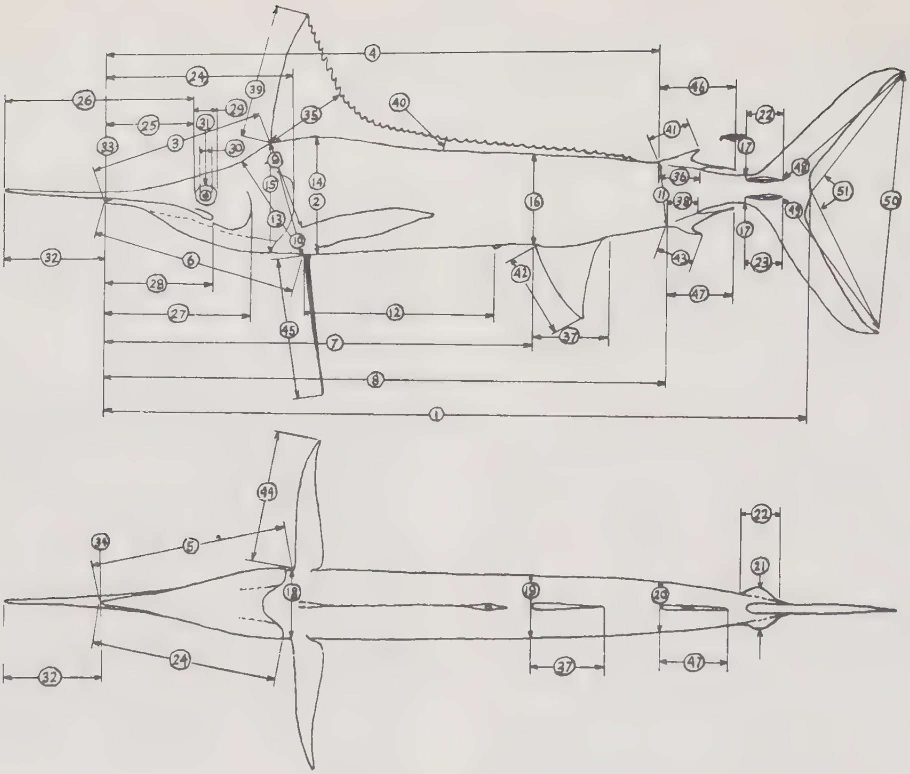

Figure 1.—Lateral and ventral views of a marlin, showing location of measurements. The numbers correspond to the numbers in the text.

6.—*Prepelvic length.*—Measured from the tip of the mandible to the origin of the pelvic fin. The latter point is the intersection of the anterior basal margin of the pelvic fin with the belly when the fin is held erect.

7.—*First preanal length.*—Measured from the tip of the mandible to the origin of the first anal fin. The latter point is determined in the same manner as the origin of the first dorsel fin (See above).

8.—*Second preanal length.*—Measured from the tip of the mandible to the origin of the second anal fin. The latter point is determined in the same manner as the origin of the second dorsal fin (See above).

9.—*Origin of first dorsal to origin of pectoral.*—This character is self-explanatory according to descriptions of these fin origins as given above (See first predorsal length and prepectoral length).

10.—*Origin of first dorsal to origin of pelvic.*—This character is self-explanatory according to descriptions of these fin origins as given above (See first predorsal length and prepelvic length). It constitutes a good indicator of the anterior depth of the body.

11.—*Origin of second dorsal to origin of second anal.*—The character is self-explanatory according to descriptions of these fin origins as given above (See second predorsal length and second preanal length). It constitutes a good indicator of the posterior depth of the body.

12.—*Origin of pelvic to vent.*—Measured from the origin of the pelvic fin (See prepelvic length) to the anterior border of the anus.

13.—*Origin of pelvic to nape.*—Measured from the origin of the pelvic fin (See prepelvic length) to the nearest point on the midline of the nape. This character gives good quantitative expression of the "hump" associated with ontogenetic stages of certain species.

14.—*Greatest depth of body.*—This character is self-explanatory. Its points of reference correspond with those for body girth as described above.

15.—*Depth of body at origin of first dorsal.*—Measured from the origin of the first dorsal (See first predorsal length), vertically to the midline of the isthmus, not including the branchiostegal membrane if it extends to the latter point. This character is a good indicator of the posterior depth of the head and may be used in connection with origin of pelvic to nape, to obtain a quantitative interpretation of the magnitude of the "hump."

16.—*Depth of body at origin of first anal.*—Measured from the origin of the first anal fin (See first preanal length), vertically to the edge of the dorsal groove. This character is a good indicator of the middle depth of the body.

17.—*Least depth of caudal peduncle.*—Measured at the precaudal transverse grooves.

18.—*Width of body at origin of pectorals.*—Measured between the origins of both pectoral fins (See prepectoral length). This character is a good indicator of the anterior width of the body and may be more accurately and conveniently obtained with the fish hanging by the tail.

19.—*Width of body at origin of first anal.*—Measured at the widest point on the vertical from the origin of the first anal fin. This character is a good indicator of the middle width of the body and may be more accurately and conveniently obtained with the fish hanging from the tail.

20.—*Width of body at origin of second anal.*—Measured according to the same procedure described for the above character. This character is a good indicator of the posterior width of the body.

21.—*Width of caudal peduncle at keel.*—Measured between the outermost point on the edge of each caudal keel (swordfish). Upper caudal keels in sailfish, spearfish and marlin.

22.—*Length of upper caudal keel.*—Measured between the points where the keel merges with the caudal peduncle anteriorly and with the caudal fin posteriorly. These points, although not well defined, may be estimated fairly accurately. Same procedure for single keel of swordfish.

23.—*Length of lower caudal keel.*—Measured according to the same procedure described above for the upper caudal keel.

24.—*Head length.*—Measured from the tip of the mandible to the most distant point on the margin of the opercle.

25.—*Snout length.*—Measured from the tip of the mandible to the most anterior point on the fleshy margin of the orbit.

26.—*Bill length.*—Measured from its tip to the most anterior point on the fleshy margin of the orbit.

27.—*Preopercular length.*—Measured from the tip of the mandible to the most distant point on the margin of the preopercle.

28.—*Maxillary length.*—Measured from the tip of mandible to the posterior end of the maxillary.

29.—*Orbit diameter.*—Measured as a horizontal distance from the most anterior point on the fleshy margin of the orbit.

30.—*Iris diameter.*—Measured as a horizontal distance from the most anterior point on the margin of the (ossified) sclera.

31.—*Interorbital width.*—Measured as the shortest distance between the uppermost point on the fleshy margin of the orbits.

32.—*Tip of mandible to tip of bill.*—This character is self-explanatory. Care must be taken that the jaws are well closed.

33.—*Depth of bill.*—Measured on the vertical passing through the tip of the mandible.

34.—*Width of bill.*—Measured on the vertical passing through the tip of the mandible.

35.—*Origin of first dorsal to edge of fin.*—Measured from the origin of the first dorsal fin (See first predorsal length) to the nearest tip (on dorsal edge) of a dorsal spine. This measurement is connection with the anterior height of the fin (see below) gives a good quantitative interpretation of the magnitude of the anterior dorsal lobe.

36.—*Length of second dorsal base.*—Measured from the origin of the second dorsal fin (See second predorsal length) to the end of the fin base. The latter point is the intersection of the posterior basal margin of the last ray with the back.

37.—*Length of first anal base.*—Measured from the origin of the first anal fin (See first preanal length) to the end of the anal groove. To the last (very short) discernible spine in the swordfish.

38.—*Length of second anal base.*—Measured according to the same procedure described above for the length of the second dorsal base.

39.—*Anterior height of first dorsal.*—Measured from the origin of the first dorsal fin (See first predorsal length) to the tip of the lobe.

40.—*Length of middle dorsal spine.*—The 25th dorsal spine measured (erect) from its intersection with the dorsal groove to its tip. This character is a good quantitative indicator of the ontogenetic changes in height undergone by the first dorsal fin.

41.—*Anterior height of second dorsal.*—Measured from the origin of the second dorsal fin (See second predorsal length) to the tip of its anterior lobe.

42.—*Height of first anal.*—Measured according to the same procedure described above for the anterior height of first dorsal.

43.—*Anterior height of second anal.*—Measured according to the same procedure described above for the anterior height of second dorsal.

44.—*Length of pectoral.*—Measured from the origin of the pectoral fin (See prepectoral length) to its tip, with the anterior basal margin of the fin perpendicular to the body.

45.—*Length of pelvic.*—Measured according to the same procedure described above for the length of the pectoral. The fin should be held straight and stretched to its full length.

46.—*Length of second dorsal.*—Measured from the origin of the second dorsal fin (See second predorsal length) to the tip of the last (suctorial) ray held straight and against the middorsal line of the back.

47.—*Length of second anal.*—Measured according to the same procedure described above for the length of second dorsal.

48.—*Length of upper caudal lobe.*—Measured from the posterior end of the upper caudal keel to the tip of the upper caudal fin lobe.

49.—*Length of lower caudal lobe.*—Measured according to the same procedure described above for the length of upper caudal lobe, but using the end of the lower keel as point of reference.

50.—*Caudal spread.*—Measured between the tips of the caudal fin lobes.

51.—*Caudal angle.*—Measured by joining three points of reference represented by the tips of the caudal fin lobes and the middle point on the posterior margin of the middle caudal ray. This character is a good quantitative indicator of the change of angulation and concavity of the caudal fin among species and ontogenetically within a species.

Counts

1.—*Dorsal spines.*—The number of dorsal spines has not been widely used as a taxonomic character in billfishes and there is reason to believe that most of the few counts reported in the literature are not accurate.

Careful inspection of the anterior part of the dorsal fin will show that the first two or three spines are very close together, and therefore difficult or impossible to count without dissection. Very often the first and even the second spine is extremely short. They are easily missed if the skin covering is not peeled off to the base of the fin and the spines separated with the point of the knife. Posteriorly, and especially in adult marlins, the dorsal spines gradually decrease in length and become very short or obsolete as the second dorsal fin is approached. This condition appears to be correlated with growth, since in the post-larval and juvenile stages of billfishes (Beebe, 1941; Arata, 1954) the first dorsal fin is continuous with the second, but in the young adult stages a gap appears externally between these two fins. This gap becomes progressively longer as the fish becomes older and is quite extensive in very large specimens.

Dorsal spine counts in billfishes without consideration of the above facts, would be inaccurate and lead to false taxonomic interpretations, when samples of widely differing age groups are compared. Dissection of the anterior part of the fin obviously should always be made, and posteriorly, attention should be paid to the magnitude of the gap and the resulting degree of external discontinuity between the first and second dorsal fins. If the distance between the last dorsal spine and the origin of the second dorsal fin is about equal to or somewhat greater than the distance between the last dorsal spine and the preceding one, no obsolete spines are then present. It is recommended that if the gap is of a magnitude indicating the existence of one or more obsolete spines the dorsal spine count be followed by the sign plus (+).

2.—*Dorsal rays.*—All rays are counted. In this fin the rays are easily made out without dissection.

3.—*Anal spines.*—Counted according to the same procedure described above for the dorsal spines. The discussion given above in connection with the dorsal spines also applies to the anal spines.

4.—*Anal rays.*—Same procedure as described above for the dorsal rays.

5.—*Pectoral rays.*—All rays are counted. Although all rays are made out in this fin without dissection, care must be taken that the posterior part of the fin is well spread out so that the very small posterior rays are not missed.

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MFR PAPER 1127

An Assessment of the South Pacific Albacore, *Thunnus alalunga*, Fishery, 1953-72

ROBERT A. SKILLMAN

ABSTRACT—As the amount of fishing effort expended in the South Pacific albacore, Thunnus alalunga *(Bonnaterre), fishery increased markedly from the mid-1960's through the early 1970's, measures of apparent abundance of albacore declined by more than 60%. Preliminary estimates of catch per unit effort for the first half of 1974 set new records, alarmingly low ones. Because of these factors and because of proposed further increases in harvesting pressure, an assessment of the fishery is needed. The albacore resource is assessed in this paper by using the generalized production model of Pella and Tomlinson. Using two measures of fishing effort, the maximum sustainable "average" yield is estimated to be 33,000-35,000 metric tons. Based on the generalized production model, a 25% increase in fishing effort over the 1971 level will result in a moderate increase in catch, 300 metric tons, or a substantial decline in catch, 6,700 metric tons, depending on the measure of fishing effort used.*

INTRODUCTION

The development of the South Pacific fishery for albacore, *Thunnus alalunga* (Bonnaterre), in its entirety and in particular that segment based in American Samoa has been described in detail by Otsu (1966) and Otsu and Sumida (1968). Their descriptions have been summarized and updated in the following paragraph.

Before the 1940's there was virtually no longline fishing in the South Pacific Ocean. After the ratification in April 1952 of the Peace Treaty between the United States and Japan, the Japanese began fishing in the western South Pacific near the Solomon Islands, principally for yellowfin tuna, *Thunnus albacares* (Bonnaterre). By late 1952, the Japanese had sent fishing expeditions as far south as lat. 15°S, and by 1953-54 they had extended their operations to lat. 25°S in the western Pacific. In 1953, a California tuna-packing firm bid for and obtained a lease from the U.S. Department of the Interior on a defunct cannery that had been built in Pago Pago, American Samoa in 1949 (Van Campen, 1954). In January 1954, seven Japanese tuna vessels began longline fishing in the vicinity of American Samoa to supply tuna for this cannery, thus establishing the albacore fishery in the South Pacific. This fishery has expanded over the years with the growth of the operations in American Samoa (Fig. 1), the increase in home-based fleets of Japan, Korea, and Taiwan, and the establishment of new bases in the South Pacific. A base was established at Espíritu Santo in the New Hebrides in 1958 and at Levuka in the Fiji Islands in 1963. Also in 1963, a second California tuna-packing firm began operations in American Samoa. The latest development occurred in 1971 when a transshipment base was established in Tahiti. Very small surface fisheries exist in Australia and New Zealand but were not considered in this paper.

In the Samoan fishery, the catch of yellowfin tuna slightly exceeded that of albacore in 1954 and 1955; thereafter, albacore has been dominant in the catch (Fig. 2). Albacore catches reached a peak in 1967 and have since declined. Catches of yellowfin tuna increased throughout the history of the fishery and remained second to albacore in all but 3 years. Catches of bigeye tuna, *Thunnus obesus* Lowe, reached a peak in 1967, when they exceeded yellowfin catches, and declined steadily through 1971. Catches of billfishes were never significant in

Pago Pago harbor and three typical Japanese longliners.

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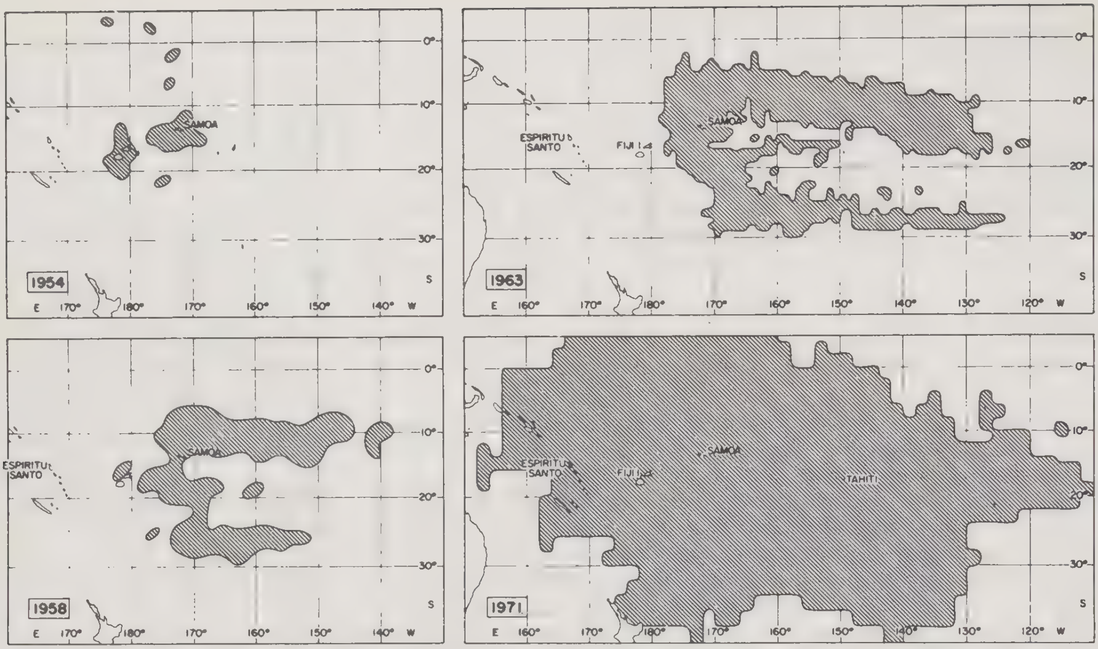


Figure 1.—Areas fished (hatched) by the longline fleet based in American Samoa in 1954, 1958, 1963, and 1971 as well as the location of longline bases (island names) in the South Pacific.

the Samoan fishery. The species trends shown in Figure 2 are not directly comparable because albacore were weighed in the round while yellowfin and bigeye tunas were weighed gilled and gutted and billfish weights were for fillets.

Other biological and fishery information relating to South Pacific albacore may be found in Isii and Inoue (1956), Koga (1961, 1962), Otsu and Hansen (1962), Yoshida and Otsu (1963), Yoshida (1965, 1971), Ishii (1967), Nakagome (1969), and Grandperrin and Legand (1971). A colorful description of the various fisheries in American Samoa, including the longline fishery for albacore, may be found in Otsu and Yoshida (1971).

Plans to expand fishing operations in Tahiti and to establish a third cannery in American Samoa stimulated this production model assessment of: 1) the effects of the fishery on the albacore population and 2) the biological potential for expansion of the fishery. In order to produce this assessment on a timely basis, first approximations of total catch for the entire South Pacific were used and the effort statistics were treated in a cursory fashion.

Since total catch data for the entire South Pacific and appropriate effort data from the fishery in American Samoa were available from 1962 to 1971, the production model assessment was limited to those years. However, those statistics that were available through 1972 were included in the figures so that as current a picture of the fishery as possible could be presented.

SOURCE DATA

Fishing Effort

For the vessels based in American Samoa, fishing effort has been measured in terms of the number of vessels fishing, size of vessels, number of trips, number of days fished, and number of hooks fished. Each of these

Unloading operations on a small longliner. Here one deckhand unties a rope used to haul several frozen fish out of the hold while another lifts a large yellowfin tuna out by hand.

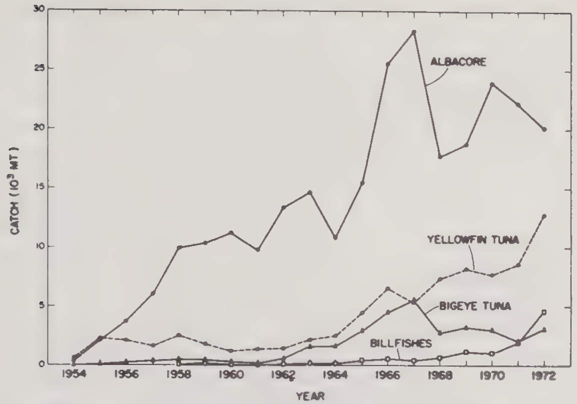


Figure 2.—Total catch in metric tons (MT) by species and by year of capture, 1954-72, for the fishery in American Samoa.

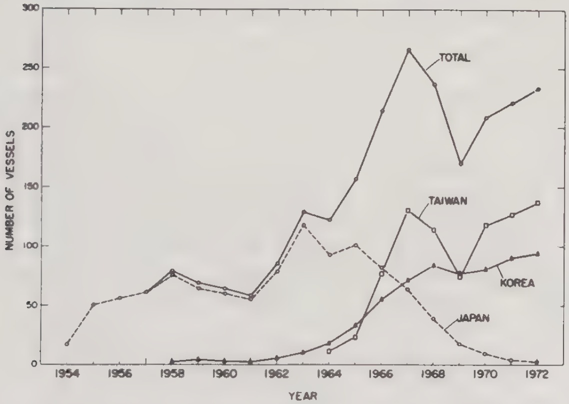


Figure 3.—The number of vessels, by nationality, fishing in the longline fishery based in American Samoa, 1954-72.

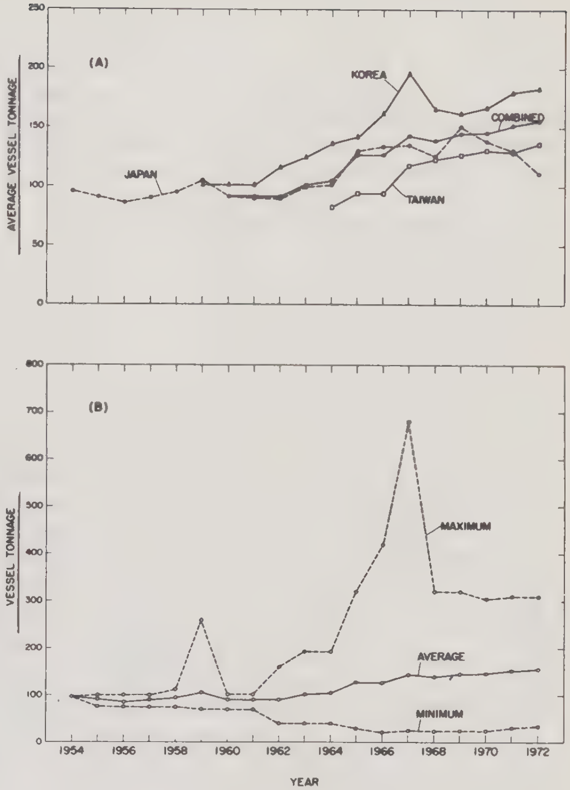
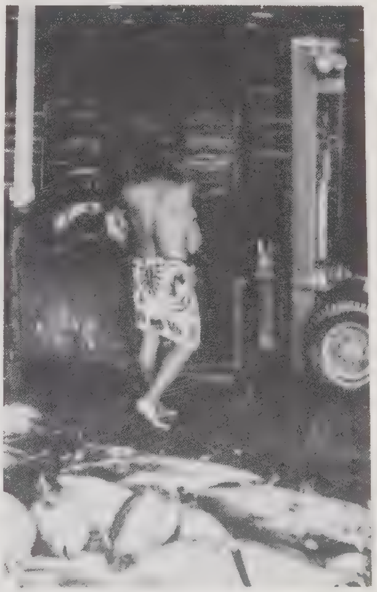


Figure 4.—Vessel tonnage for the fishery in American Samoa. A. Average vessel tonnage by nationality and for all nations combined (including those of undetermined nationality). B. Maximum, average, and minimum vessel tonnage for all nations combined (also including those of undetermined nationality).

measures will be presented to illustrate the historical development of the fishery while the latter two measures will also be used in the assessment of the effect of the fishery on the albacore population. Measures of fishing effort were available for home-based fleets of Japan, Korea, and Taiwan but were not used in this report because: 1) the percent of trips covered for some nations was low, 2) the time series was too short or interrupted for some nations, 3) albacore catches were usually incidental to fishing directed toward other tunas, and 4) these data would have had to be standardized to the Samoan data in any case.

Effort measured in number of vessels was obtained from cannery records and represents a complete sample of the fleet (Fig. 3). From a low of 18 vessels in the first year of the fishery, 1954, the number of vessels operating in the fishery increased steadily to a peak of 266 in 1967. This peak was a result of increasing representation of Korean and Taiwanese vessels and a fairly large component of Japanese vessels, although Japanese representation was actually decreasing at the time. The decline following 1967 resulted from the continued withdrawal of Japanese vessels and some contractual problems with the remaining vessels. In 1970-72, the number of vessels in the fleet again increased. In addition to this increase in number, the average size of vessels increased steadily from a low of 86 gross tons in 1956 to 156 gross tons in 1972 (Fig. 4). The maximum and minimum vessel tonnages have shown marked yearly fluctuations. The maximum increased from a low of 96 gross tons in 1954 to a peak of 680 gross tons in 1967 and stabilized at about 310 gross tons between 1968 and 1972.



Loading fish at a Samoan cannery.

The minimum decreased from a high of 96 gross tons in 1954 to a low of 20 in 1966.

The number of fishing trips made by the Samoan fleet was obtained from cannery records and represents a total sample of the fleet (Fig. 5). It has shown a highly oscillatory pattern over the history of the fishery. The number of trips made by Japanese vessels increased rapidly from 1954 to 1958, declined until 1961, increased to a peak in 1963, and declined steadily throughout the remaining years. Korea entered the fishery in 1958, but the number of fishing trips did not increase substantially until 1963. In 1964, Taiwan entered the fishery and has shown a rapid increase in fishing effort. The time trend for trips followed the same general pattern as that for number of vessels up to the peak in 1967. Trips by Taiwanese vessels showed the same decline in the late 1960's and rise in the early 1970's as the number of Taiwanese vessels; however, Korean trips showed a steady increase until 1969. The result was that the number of trips seemed to be stabilized whereas the number of vessels was increasing.

Data on the number of days spent fishing by each nation in the Samoan fleet (Fig. 6) from 1957 through part of 1972 were collected from cannery records. These data followed the same general trends shown by the other measures of effort, except for the last few years. This measure of fishing effort indicated that fishing intensity increased through 1972, when fishing effort exceeded that in the peak catch year 1967.

Because logbook records were obtained from a different proportion of the fleet each year, the number of hooks fished for 1960-72 was estimated from total catch, number of albacore per 100 hooks, and average weight of albacore in the fishery. Although it appeared that the Samoan fleet may have been directing an increasing amount of effort toward yellowfin tuna, fishing effort was not adjusted to take this potential effect into consideration. The numbers of hooks fished were at a low level in the early years but increased rapidly through 1967 (Fig. 7). The decline in number of hooks in 1968 resulted primarily from the withdrawal of Japanese vessels from the fishery. Following this decline, there seemed to be a leveling of effort at about 36 million hooks, which agrees with the trend shown by the number of trips but neither with the number of vessels nor with the number of days fished.

Total Catch

Catch data for the South Pacific longline fishery were obtained from cannery reports in American Samoa for 1954-72, from Fisheries Agency of Japan, Research Division (1965, 1966, 1967a, 1967b, 1968, 1969, 1970, 1971, 1972, 1973, 1974) for 1962-72, and from the Federation of Japan Tuna Fisheries Cooperative Associations and Japan Tuna Fishermen's Cooperative Association (1967-72) (hereafter referred to as the Asian Tuna Conference proceedings) for 1962-71. These data (Fig. 8) were used in the fitting of the generalized production model. Catch data for Japanese operations for the years 1953-59 and 1961 were obtained from Tuna Fishing (published monthly by the All Japan Investigative Conference of Tuna, Misaki Branch, c/o Kanagawa Prefectural Fisheries Experimental Station, Misakimachi, Miura-shi, Kanagawa, Japan) and presented in Figure 8 to give some idea of the trends in catches for that portion of the fishery not operating out of American Samoa. However, since these latter data were incomplete to an unknown degree, they were not used in fitting the generalized production model.

In order to convert catch reported in numbers to catch in weight, average weight was calculated using data from the Samoan fishery (Fig. 9). These averages were calculated in kilograms for 1962 through 1972 by "South Pacific Ocean Region" and "Eastern Pacific Ocean Region" as defined by the Fisheries Agency of Japan, and for the entire South Pacific (a weighted average). The average size of albacore has decreased in the "South Pacific Ocean Region" where most of the fishing effort has been expended, but this decrease in size may be due to the expansion of the fishery southward where small albacore occur. In the "Eastern Pacific Ocean Region" where the Samoan fleet fishes only seasonally and then only recently and where home-based foreign fleets fish mostly for yellowfin and bigeye tunas, the average weight showed no trend over years.

In the early years of the fishery up

Table 1.—Albacore catch in metric tons (MT) for the South Pacific Ocean. Catches in parentheses were estimated from 1970 catches (and 1971 average fish weights for Japan) because 1971 data were not available.

Year	Category	Catch (MT)				CPUE		Estimated total effective effort	
		Japan	Korea	Taiwan	Total	MT/10³ hooks	MT/*day*	Hooks (× 10⁶)	Days (× 10³)
1962	Nation	28,352	—	298	28,650			19.267	17.517
	American Samoa				13,326	1.4870	1.6356	8.962	8.147
	Grand total				41,976			28.229	25.664
1963	Nation	23,762	—	608	24,370			25.296	20.281
	American Samoa				14,650	0.9634	1.2016	15.207	12,192
	Grand total				39,020			40.503	32.473
1964	Nation	14,136	—	73	14,209			16.857	12.671
	American Samoa				10,791	0.8429	1.1214	12.802	9.623
	Grand total				25,000			29.659	22.294
1965	Nation	10,871	—	50	10,921			14.097	10.535
	American Samoa				15,459	0.7747	1.0366	19.955	14.913
	Grand total				26,380			34.052	25.448
1966	Nation	16,534	0	0	16,534			18.918	15.512
	American Samoa				25,570	0.8740	1.0659	29.256	23.989
	Grand total				42,104			48.174	39.501
1967	Nation	9,670	1,306	604	11,580			15.785	12.086
	American Samoa				28,310	0.7336	0.9581	38.591	29.548
	Grand total				39,890			54.376	41.634
1968	Nation	5,413	1,262	4,206	10,881			19.719	15.321
	American Samoa				17,723	0.5518	0.7102	32.119	24.955
	Grand total				28,604			51.838	40.276
1969	Nation	4,489	4,924	3,398	12,811			22.111	16.256
	American Samoa				18,731	0.5794	0.7881	32.328	23.767
	Grand total				31,542			54.439	40.023
1970	Nation	5,598	4,673	3,707	13,978			24.570	16.206
	American Samoa				23,876	0.5689	0.8625	41.969	27.682
	Grand total				37,854			66.539	43.888
1971	Nation	(6,437)	(4,673)	5,863	16,973			31.052	23.639
	American Samoa				22,193	0.5466	0.7180	40.602	30.909
	Grand total				39,166			71.654	54.548

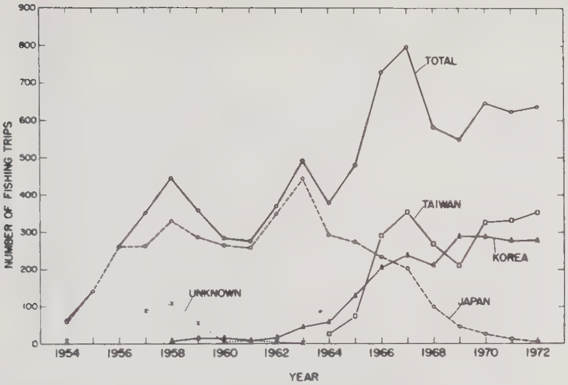


Figure 5.—Total number of fishing trips by nationality of vessels for the fishery based in American Samoa, 1954-72.

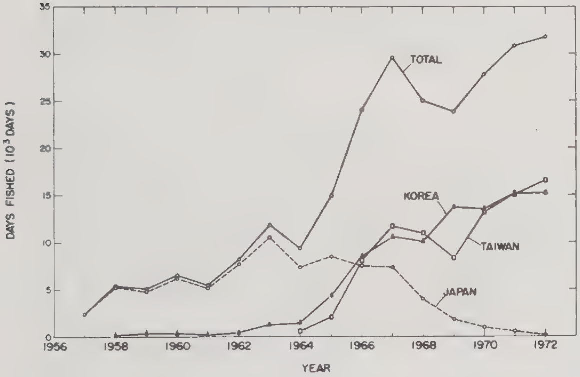


Figure 6.—Total number of days fished, by nationality of vessels, for the fishery based in American Samoa, 1957-72.

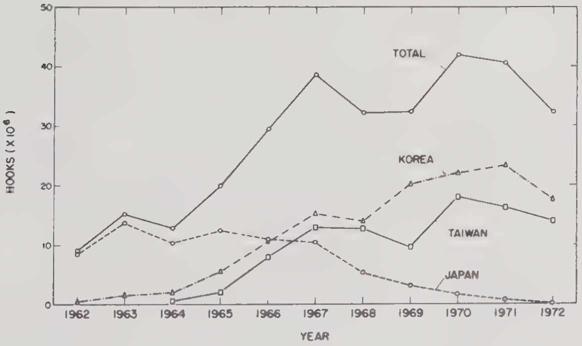


Figure 7.—Effort in hooks by nationality of vessel for the fishery based in American Samoa, 1960-72.

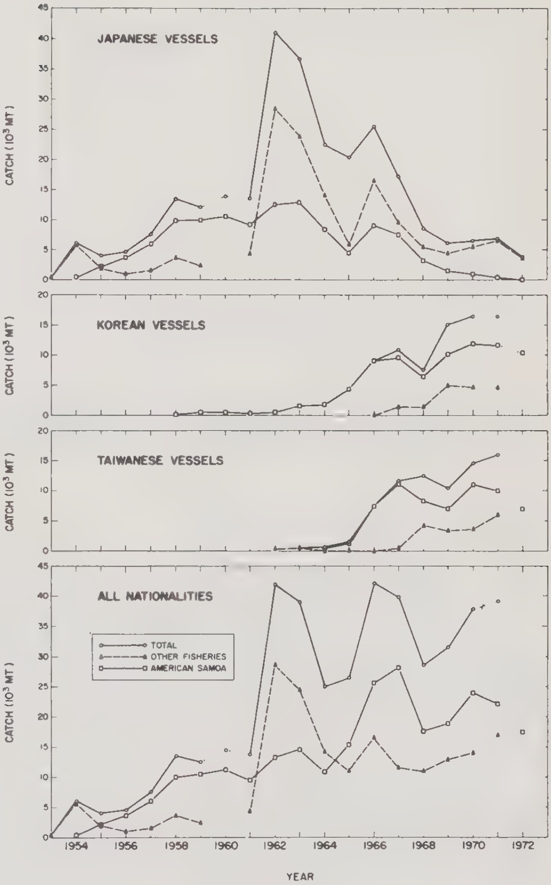


Figure 8.—Catch of albacore by nationality of vessels for the fishery in American Samoa and all other fisheries in the South Pacific. Dotted lines were used where data were missing or where catches were estimated from incomplete data.

through 1961, it appeared that the Samoan fishery constituted the major portion of the South Pacific albacore fishery (Fig. 8); however, these data were apparently incomplete and, therefore, not fully reliable. In 1962, when reliable data became available, the Samoan operations accounted for only 31.7 percent of the total catch. The actual catch and the proportion of the catch landed by the Samoan fleet increased steadily through 1964, when the proportion reached 58.6 percent, until 1967 when the fleet accounted for 71.0 percent of the catch. Following 1967, the Samoan operations accounted for about 60 percent of the total catch. This decrease in dominance of the Samoan fleet was due mainly to increased catches by other fleets.

Catches of albacore by Japanese vessels based in Samoa and elsewhere increased from 1953 through 1962, decreased through 1969 as the vessels withdrew from the albacore fishery. Incidental catches of albacore increased slightly in 1970-72. Catches of albacore by Korea and Taiwan seemed to have stabilized after an initial growth phase when they entered the fishery. For both nations, the operations based in American Samoa accounted for the largest share of their albacore catches.

ANALYSIS

Index of Relative Abundance

Index of relative abundance or catch per unit of effort (CPUE) for the fishery based in American Samoa was calculated in terms of catch in numbers of albacore per 100 hooks

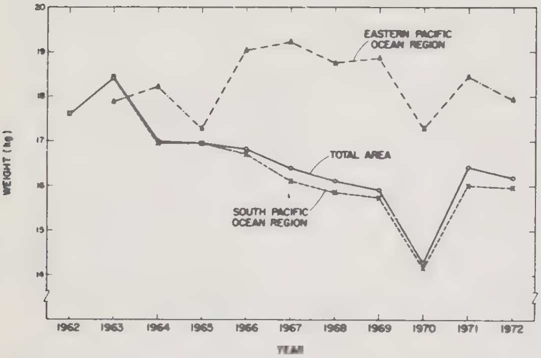


Figure 9.—Average weight of albacore for the year of capture by ocean area using data from the Samoan fishery. The 1971 and 1972 weights were estimated from actual length measures and historical trends in condition factor.

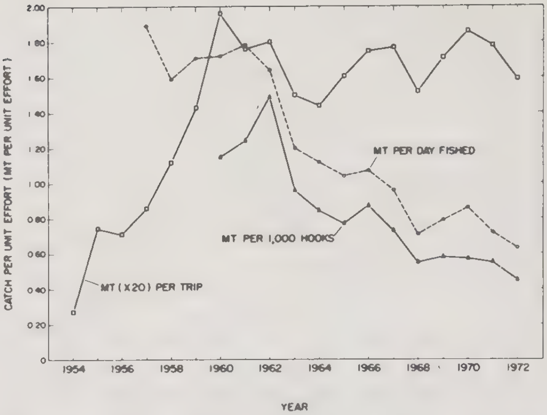


Figure 10.—Annual estimates of indexes of population abundance (CPUE) of albacore in terms of metric tons (MT) per trip, per day fished, and per 1,000 hooks as determined for the fishery based in American Samoa.

(converted to metric tons per 1,000 hooks), in metric tons per day fished (Table 1), and in metric tons per fishing trip. All indexes of relative abundance were calculated as ratio of averages estimators for each year (total catch divided by total effort).

CPUE in trips did not exhibit the same trend with time as the other indexes of abundance (Fig. 10) and was not, I felt, a valid measure of albacore abundance. The increasing CPUE in trips from 1954 through 1960 was probably due to an increase in days fished per trip as the fishery expanded into new grounds (Otsu and Sumida, 1968). Following 1965, at least until 1969, the fishery continued to expand but not as rapidly as in the preceding years (Yoshida[1]). Hence, the fluctuations seen over this time period were probably the result of a decreasing population density, a slight increase in the proportion of the population being harvested due to an expansion of the fishing grounds, a decrease in number of trips, and an increase in the number of days fished per trip. Because of these complications in the interpretation of the historical trend in these data, CPUE in trips was not used in fitting the generalized production model.

CPUE in days fished and CPUE in hooks fished followed similar trends with time, except in 1960-61. Differences in these early years were ascribed to errors in CPUE in hooks since this statistic was estimated from 2.5 percent and 8.1 percent of the total trips made by the fleet. Because of these differences and because CPUE in days fished was calculated from a complete sample of the fleet for all years, CPUE in days fished was considered the more accurate index of relative abundance. For comparative purposes, however, both of these indexes of abundance were used to estimate total effective effort and to calculate the generalized production model.

Total Effective Effort

The estimates of total effective effort, in terms of hooks and days fished by the Samoan fleet, expended in catching albacore in the South Pacific were calculated using total catch data and CPUE statistics derived in previous sections (Table 1). Since Samoan logbook records giving counts of hooks were a subsample of the whole Samoan fleet, estimates of effective effort were calculated for the Samoan fishery as well as for the catch outside the Samoan fishery. Total effective effort was obtained by summing these two estimates. Hence, by using the CPUE statistics calculated for the Samoan fishery, the effort expended by the Japanese, Korean, and Taiwanese fleets not based in Samoa was standardized in terms of the albacore fishery in American Samoa. Since Japanese vessels seemed to direct much of their effort toward southern bluefin tuna, *Thunnus maccoyii* (Castelnau), and bigeye tuna, the estimated number of hooks should have been much less than was actually fished. The same should have been true for Korean and Taiwanese data but to a lesser degree because a smaller proportion of their fishing seemed directed toward other species.

The amount of fishing effort expended by the non-Samoan fleet fluctuated from year to year but seemed to remain at about the same level from 1962 to 1970. In 1971, there may have been a trend upward in fishing effort. Over this same 10-year period, the effort expended by the Samoan fleet increased markedly (about 450 percent). The result of these two trends was that the total effective effort expended in the capture of albacore increased by about 250 percent.

Generalized Production Model

Although a wealth of biological knowledge on the South Pacific albacore does not exist and in particular information is lacking on mortality, individual growth, and recruitment that is required to use a dynamic pool model (Beverton and Holt, 1957; Ricker, 1958), there nonethless is a need to assess the state of the stock. Therefore, the generalized production model of Pella and Tomlinson (1969), requiring only catch and effort data, was used in this paper. However, this model makes several assumptions regarding population processes and handling of effort data in order to allow for the simplification of certain dynamic processes of populations. These assumptions are as follows: 1) The population is a closed, distinct, self-sustaining unit. It is generally believed that there are separate albacore populations in the North and South Pacific for the following reasons: a) areas of high catches or catch rates do not straddle the equator, b) areas of peak catches in both the North and South Pacific occurring in their respective winter months are at the poleward extremes of the fishery and then tend to move to middle latitudes as "summer" approaches, c) albacore of all ages are apparently in both the North and South Pacific, d) spawning seems to occur in the North Pacific in areas and seasons that are distinct from spawning in the South Pacific, e) no albacore tagged in the North Pacific have ever been recaptured in the South Pacific. As on any question, there is no uniformity of opinion here. Grandperrin and Legand (1971) argued on the basis of limited experiments with deep-fishing vertical longline gear in waters near New Caledonia (lat. 12°-23°S) and in French Polynesia (lat. 10°-25°S) that it is possible for the exchange of small fish as well as large fish across the equator. Their hypothesis is based on high catch rates of large fish at 200-300 m (greater than in the traditional grounds above 150 m) and on the occurrence of two small albacore (4.0 and 9.5 kg) at these depths in the experiments near New Caledonia. More work needs to be done in this area (see also Saito, 1973). 2) The concept of equilibrium holds for the South Pacific albacore. I do not suggest that the population is necessarily in equilibrium but rather that the population always tends toward a stable population size in response to changes in mortality (primarily fishing effort). 3) Although I assume that the concept of equilibrium holds, I do not assume that equilibrium is reached instantaneously with changes in fishing effort. The age of maturity for albacore is sufficiently old and the albacore contributes significantly to the fishery for so long that I feel it is unreasonable to expect the population to respond instantaneously to changes in fishing effort. Hence, Gulland's procedure (Gulland, 1969, p. 120), which averages fishing effort over some mean time period during which a year class contributes significantly to the catch, was used to adjust for non-instantaneous response of the population to changes in fishing effort. 4) I have assumed that the catchability coefficient, q, is constant. There is no evidence that any gear modification, change in the nationality of the fleet, or change in species sought has caused any change in q.[2] The possibility of changing q as the fishery has expanded into new grounds, some of which yield fish smaller than the average size in the fishery, has not been investigated. 5) Sufficient data are available over a time period when a large population change occurred (a reduction of 56-62 percent in relative abundance over an 11-year period) so that the parameters of the production model can be estimated efficiently.

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[1] Yoshida, H. O. The American Samoa Longline Fishery, 1966-71. Manuscript.

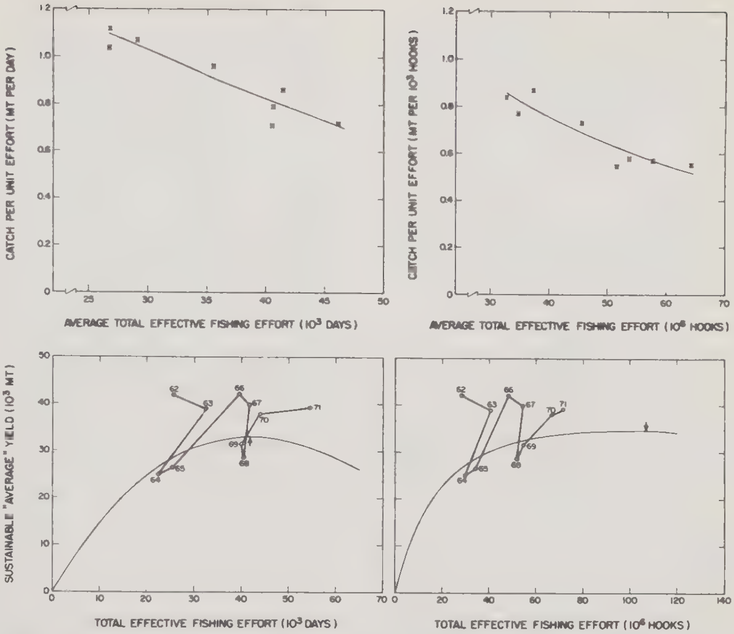

Figure 11.—Plots of catch and fishing effort data for the South Pacific albacore fishery showing the equilibrium relationship between CPUE and fishing effort and the relationship between sustainable "average" yield and fishing effort for the generalized production model with effort data in terms of number of days fished and number of hooks fished and with an averaging time ($\overline{T}_i$) equal to 3 years. Arrows indicate location of MSAY (Maximum Sustainable "average" yield) on the stock production curves.

The generalized production model of Pella and Tomlinson (1969) was obtained for the South Pacific albacore fishery by entering catch in metric tons and effort in both number of days fished and number of hooks fished into PRODFIT, a least squares nonlinear regression algorithm using Gulland's equilibrium approximation technique (Fox, 1972). Four parameters of management interest were derived from the model using PRODFIT, namely $\overline{m}$, $CPUE_{opt}$, f_{opt}, and MSAY. The phrase maximum sustainable "average" yield (MSAY) was substituted for the well-known phrase maximum sustainable yield (MSY) to denote that the sustainable yield will fluctuate even though fishing effort and the catchability coefficient remain constant. The least squares procedure finds a solution of the general production model, using CPUE as the dependent variable, that results in the smallest residual sum of squares compared to all other possible solutions. Thus, this solution is a measure of central tendency, but not a true average. Calculating the curve of

[2] Skillman, R. A. 1974. Further investigations on the population dynamics of the South Pacific albacore fishery. Unpublished report filed at the Southwest Fisheries Center, National Marine Fisheries Service, NOAA, Honolulu Laboratory, Honolulu, HI 96812.

Table 2.—Generalized production model for the South Pacific albacore fishery, 1962-71.

$\bar{T}_i$	$\hat{m}$	$\widehat{CPUE}_{opt}$	$\widehat{MSAY}$	$\hat{f}_{opt}$	MSQ
	Model using fishing effort in days fished				
Years		*MT/day*	*10^3 MT*	*10^3 DAYS*	
2	2.24	0.825	35.385	42.900	0.1351
3	1.62	0.791	33.072	41.801	0.0613
4	0.61	0.584	33.473	57.291	0.1210
	Model using fishing effort in hooks fished				
Years		*MT/10^3* hooks	*10^3MT*	*10^6 hooks*	
2	0.64	0.477	35.913	75.279	0.1588
3	0.25	0.325	34.665	106.761	0.0769
4	0.15	0.262	33.719	128.512	0.1351

sustainable "average" yields (SAY) from the above solution and finding the maximum of this curve produces an estimate of MSAY. The SAY curve may not appear to be the best possible fit to the observed yield/effort data because the curve represents equilibrium yield whereas the observed values represent transient yields (Fig. 11). In addition, the SAY/total effective effort curve is derived from the actual least squares solution of the production model. The other parameters are defined as follows: *m* describes the symmetry of the curve between SAY and fishing effort and the concavity of the curve between CPUE and effort, for example when $m = 0.0$, the SAY curve is asymptotic and the CPUE curve is markedly concave upwards, when $m \rightarrow 1$, the SAY curve is skewed (Gompertz model) and the CPUE curve is slightly concave upwards, and when $m = 2.0$, the SAY curve is symmetric (logistic or Schaefer model) and the CPUE curve is a straight line; and CPUE$_{opt}$ and f_{opt} are estimates of the index of population abundance in metric tons per unit effort and the amount of total effective fishing effort expended at the point of estimated MSAY.

Since no age or size group composition studies have been performed on the South Pacific albacore population, averaging times for the equilibrium approximation technique were based on the number of age groups present in the Japanese longline fishery for albacore in the North Pacific. Otsu and Uchida (1963) recognized six age groups, ages 2 to 7, in the North Pacific fishery with age group 2 comprising a small proportion of the catch; hence a year-class contributed significantly to the catch for approximately 5 years. Using this information, an averaging time ($\bar{T}_i$) of 2 or 3 years for Gulland's approximation seemed appropriate for the South Pacific fishery. For comparative purposes, an averaging time of 4 years was also included.

Results of the production model analysis are presented in Table 2 and Figure 11. On the basis of mean sum of squares (Table 2), an averaging time of 3 years resulted in the best fit with an averaging time of 4 years being second best for fishing effort in both days and hooks. From the distribution of the observed data points (averaged) relative to the fitted values (Figure 11), it is obvious that the generalized production model using $\bar{T}_i = 3$ years can be used for predictive purposes within the range of the observed fishing effort.

Since the production models for effort in both days and hooks fished indicated a MSAY of 33,000-35,000 metric tons, the major differences between the models was in the estimation of CPUE$_{opt}$ and f_{opt} and in the shape of the SAY and CPUE curves. It must be remembered that both CPUE$_{opt}$ and $\hat{f}_{opt}$ are in terms of the fleet based in American Samoa; therefore, the CPUE$_{opt}$ and f_{opt} estimates refer only to vessels fishing for albacore in the same manner as the Samoan fleet. In particular, the total amount of fishing effort expended in the South Pacific will be considerably in excess of the values used or predicted in this analysis because much of the fishing effort is directed towards yellowfin, bigeye, and southern bluefin tunas. If this were a management situation, $\hat{f}_{opt}$ would have to be partitioned and adjusted for each segment of the South Pacific longline fishery.

DISCUSSION

Based on the generalized production models given in Table 2 and Figure 11, it must be concluded that the South Pacific albacore fishery has reached or nearly reached the level of MSAY, given the current constitution of the fishery. Any further increase in fishing effort, deployed in the same manner as the present fishing effort, will result in a further decline in CPUE, without any significant increase in yield and probably a decrease. If the South Pacific fishing fleet were to change its fishing strategy, for example by harvesting different age groups at different intensities or possibly by fishing for adult fish at greater depths in the middle South Pacific latitudes, the estimated MSAY for the stock might change.

Because the shape of the SAY curve was different for the two models presented in this paper as well as for models not reported on here that used a slightly different estimate of total catch and different measures of CPUE, I do not have a great deal of confidence in the shape of the right-hand limb of the SAY curve. With the above statement in mind and using the two production models presented here, if a 25 percent increase in fishing effort over the 1971 level is hypothesized, the estimates of SAY would decrease to 27,900 metric tons (CPUE = 0.57 metric ton/day) from a 1971 SAY level of 30,800 metric tons for the model using effort in days fished, or increase to 34,300 metric tons (CPUE = 0.44 metric ton/10^3 hooks) from a 1971 SAY of about 34,000 metric tons for the model using effort in hooks fished. Based on this analysis, the SAY cannot be increased appreciably and might decline significantly with a 25 percent increase in effort.

While a number of assumptions regarding the use of the generalized production model and the handling of the catch and effort data have been made, none of these assumptions are regarded as being unreasonable. Nor would slight departures from any of the assumptions invalidate the results from this "first cut" analysis. If the biological information were available to verify the assumptions or to make adjustments to the data as called for, sufficient data would be present to apply a more sophisticated approach.

ACKNOWLEDGMENTS

Thanks are extended to the many National Marine Fisheries Service employees who manned our field station in Pago Pago, and to the staff members of the Office of Marine Resources, Government of American Samoa who subsequently took over the data collecting responsibilities in Pago Pago. Special thanks are given to Ray Sumida, Honolulu Laboratory, who has supervised the management of the data obtained from this fishery. The excellent cooperation received from personnel of the tuna canneries of Star-Kist Foods, Inc. and Van Camp Sea Food Co. is gratefully acknowledged. I am indebted to James C. Olsen, Auke Bay Fisheries Laboratory, NMFS, and Robert C. Francis, Inter-American Tropical Tuna Commission, who reviewed this paper and offered valuable, constructive criticisms of it.

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MFR PAPER 1167

A brief look at regional fish-price fluctuations since 1941.

Fish Prices: Historical Trends in Southern California Commercial Fisheries

GARY STAUFFER, ALEC MacCALL, and BRUCE WAHLEN

*ABSTRACT—Ex-vessel prices for southern California commercial fishery resources are reviewed for the period 1941 to 1972. The annual average prices were deflated by the wholesale price index. Prior to 1960 the ex-vessel prices for wetfish species, Pacific sardine (*Sardinops caeruleus*), Pacific mackerel (*Scomber japonicus*), jack mackerel (*Trachurus symmetricus*), northern anchovy (*Engraulis mordax*), and market squid (*Loligo opalescens*), were dominated by the scarcity of sardines and Pacific mackerel. Anchovy prices in the mid-1960's declined as the result of the instigation of a reduction fishery. More recently, anchovy prices have increased as a result of the collapse of the Peruvian anchoveta fishery. Prices for the tunas—yellowfin tuna (*Thunnus albacares*), skipjack tuna (*Katsuwonus pelamis*), bluefin tuna (*Thunnus thynnus*), and albacore (*Thunnus alalunga*)—surged upward with post-World War II inflation, but domestic prices dropped in the mid-1950's due to Japanese imports of frozen and canned tuna. Prices in the 1960's increased with expansion of the world tuna market. The market for the U.S. production of Pacific bonito (*Sarda chiliensis*) was taken over by Peruvian imports in the mid-1950's and domestic ex-vessel prices declined. By the mid-1960's, Peruvian imports had decreased, bonito prices increased, and the U.S. fishery was rejuvenated. The market fish, the larger migratory coastal species—yellowtail (*Seriola dorsalis*), white seabass (*Cynoscion nobilis*), California barracuda (*Sphyraena argentea*), and the less migratory rockfishes (*Sebastes *spp.)—are sold fresh and frozen in local retail fish markets. Prices for this group have been relatively constant except during periods of increased availability.*

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INTRODUCTION

Fish prices, like other high-protein food prices, have been rising drastically in recent years. Conditions of limited supply, increasing demand, and increasing operating expenses, appear to be fundamentally responsible for this rise in prices, which, spurred on by inflation, is quickly putting many kinds of fish in the category of luxury foods. While recent changes in prices tend to be most easily remembered, price and catch histories of various species of fish commonly landed in southern California show many interesting fluctuations over the years. An examination of these time series reveals some of the many considerations which determine the price of fish paid to fishermen (ex-vessel price). These price and catch histories are presented with little more than a brief discussion of trends and events which appear to have been influential. For detailed technical analyses see Perrin and Noetzel (1970) and O'Rourke and DeLoach (1971).

Commercial fish transactions in California require sales receipts recording such information as species, quantity, and price. The information on these landings receipts is processed by the California Department of Fish and Game and is published annually as a Fish Bulletin entitled *California Marine Fish Landings*. Included are extensive tables of catch information such as species, location of landings, poundage, and value. Average prices paid for fish landed were calculated by dividing total value by total California landings. This average will tend toward the price paid for the largest quantities of fish, and may not reflect prices paid in periods of low landings.

Since the purchasing power of the dollar was generally falling during the period 1941 to 1972, the prices have been deflated by the wholesale price index (all commodities) with 1941 as the base year[1]. By adjusting for inflation in this way, comparison of fish prices between years is more meaningful, particularly during the post-World War II and recent inflationary periods (Fig. 1). Discussion of prices will generally refer to adjusted prices. The scale of prices changes from graph to graph in order to present the most possible detail.

For convenience we have divided the fish species into three broad categories: wetfish, the tunas, and market fish. Species in the same category tend to share traits such as similar (or identical) fishing fleets, processing, and marketing, and thus often show similar price relationships. Some species such as market squid do not conveniently fall into any category while Pacific

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[1] See "Economic Report of the President," transmitted to the Congress January 1973 together with the annual report of the Council of Economic Advisors (Table C-48).

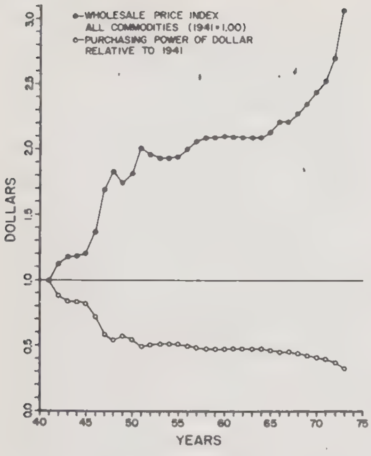

Figure 1.—Wholesale price index for all commodities standardized to U.S. $1.00 for 1941.

bonito and California yellowtail could possibly be included in more than one category.

WETFISH

The wetfish group is composed of the Pacific sardine (*Sardinops caeruleus*), Pacific mackerel (*Scomber japonicus*), jack mackerel (*Trachurus symmetricus*), northern anchovy (*Engraulis mordax*), and market squid (*Loligo opalescens*). The term "wetfish" derives from the procedure employed in canning these species: the fish is first packed raw, sealed in the can, and is afterward cooked and sterilized by heat. The processing equipment is the same for all these species, allowing considerable interchangeability in the species accepted by the canneries, particularly between sardines, Pacific mackerel, and jack mackerel. The wetfish species are similar in habitat and behavior, tending to school in open waters in the southern California bight, and are fished interchangeably by a specialized local purse-seine fleet. In the early 1940's, a large segment of the wetfish fleet operated out of Monterey, but collapse of the northern sardine fishery led to consolidation of the fleet in San Pedro.

Pacific Sardine

In the 1930's and 1940's the Pacific sardine (Fig. 2) supported one of the largest fisheries in the world, but a long period of decline, punctuated by brief recoveries, led to final collapse of the sardine stocks and fishery in the 1960's. The sardine industry had an extensive market as well as an immense investment in processing equipment, resulting in prices that were very sensitive to changes in availability. The degree to which the sardine dominated the wetfish industry is reflected in the trends in the prices of the other wetfish during the sardine shortages of 1948, 1953, and 1957. By the early 1960's the foreign sardine markets were lost to African and Japanese suppliers who sold at prices considerably below production costs in California. Since the mid-1960's, sardines have been frozen for sport fishing bait which commands a much higher price than fish destined for canning. A fishing moratorium, including use for bait, has been in effect in California since 1973, with catch taken incidental to other fishing operations going for canning and reduction only.

Pacific Mackerel

The Pacific mackerel (Fig. 3) fishery and market was conducted independently of the overshadowing sardine industry, although in times of sardine shortage, Pacific mackerel was the first alternative. While the main gear was the purse seine of the wetfish fleet, an independent "scoop" fleet[2] sometimes accounted for over half the annual

[2] The "scoop" fleet harvested Pacific mackerel by attracting them with a slurry of ground sardines or anchovies (called chum) and scooping up the feeding mackerel with large hand-held dip nets.

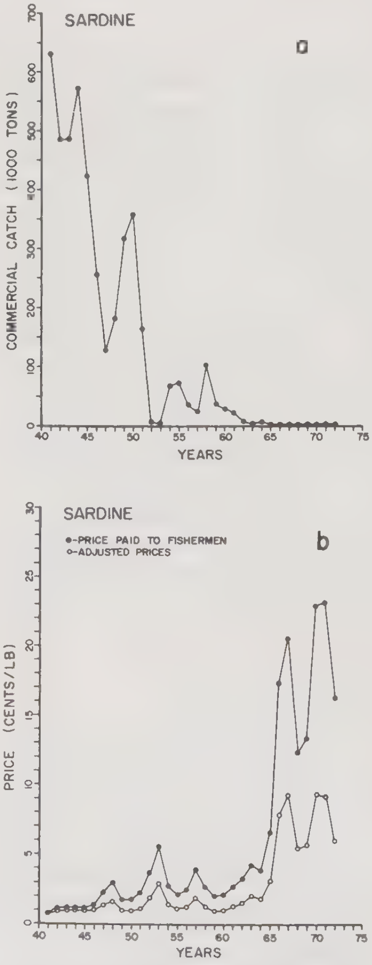

Figure 2.—Annual Pacific sardine a) landings in California, and b) average ex-vessel prices paid to fishermen for the years 1941 through 1972.

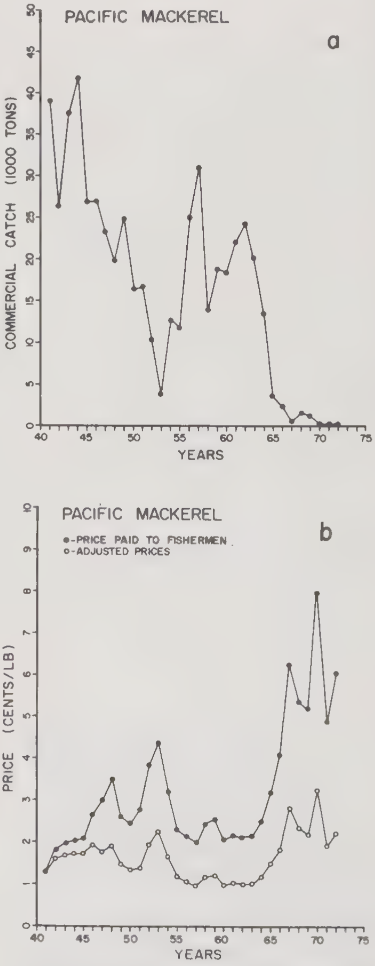

Figure 3.—Annual Pacific mackerel a) landings in California, and b) average ex-vessel prices paid to fishermen for the years 1941 through 1972.

catch. The extreme shortage in 1953 coincided with a sardine shortage, resulting in record prices. Pacific mackerel were also sold to fresh fish markets in small quantities, fetching prices considerably higher than those paid by the canneries. The Pacific mackerel fishery also experienced collapse in the mid-1960's, aggravating wetfish processor difficulties arising from the loss of the sardine fishery. A moratorium on the take of Pacific mackerel has been in effect since 1970, with the small incidental catch going to the fresh fish markets.

Jack Mackerel

Jack mackerel (Fig. 4) were first fished heavily during the sardine shortage that started in 1947. Generally, the industry did not discriminate between the two mackerels and set the same price for both species, with an occasional premium on Pacific mackerel. Once jack mackerel was shown to be an acceptable substitute in the sardine and Pacific mackerel market, it took on the role of filling in shortages of the more desirable species. With the continued decline in preferred species, local jack mackerel resources were quickly used up, and the fishery expanded to the offshore islands and banks of southern California where nearly all catches are now made. Jack mackerel, which is also used extensively in pet food manufacture, is now the main wetfish canned in California. The price peaks prior to 1955 were stimulated by occasional short supplies of sardines and Pacific mackerel. These shortages encouraged greater jack mackerel harvests. On the other hand the price rise in the mid-1960's is a market response to decreased availability of both Pacific mackerel and jack mackerel.

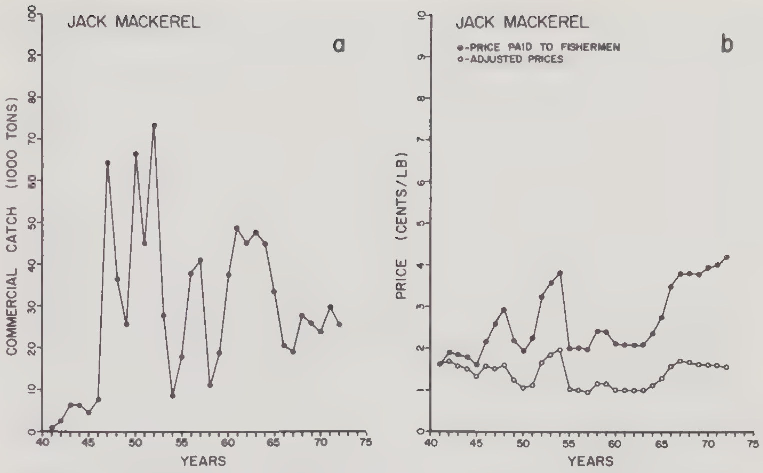

Figure 4.—Annual jack mackerel a) landings in California, and b) average ex-vessel prices paid to fishermen for the years 1941 through 1972.

Northern Anchovy

Canning of anchovies (Fig. 5) "sardine style" was attempted during the sardine shortage of the mid-1950's, but this was discontinued by 1958 due to processing difficulties and poor consumer acceptance. The low price in the late 1950's reflects low demand. While making a good pack, anchovies could not be marketed under a "sardine" label, and the California species was too large for acceptance in European markets. In view of the extreme abundance of the species and the economic plight of the wetfish fleet, an experimental reduction[3] fishery was initiated amid much controversy in 1965. With this decision, landings quickly increased and prices decreased, being dictated by world fish and soybean meal prices. A severe world shortage of protein meal arising from the collapse of the Peruvian anchoveta fishery and weather damage to the 1972 U.S. soybean crop caused prices to double and even triple in 1973, returning to inter-

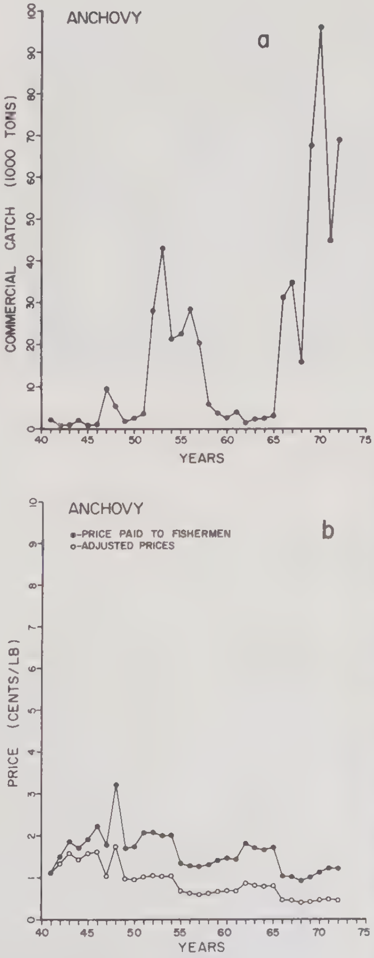

Figure 5.—Annual northern anchovy a) landings in California, and b) average ex-vessel prices paid to fishermen for the years 1941 through 1972.

Loading anchovies into well of a San Pedro wetfish seiner. Photo courtesy of the Los Angeles Times.

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[3] Reduction is the processing of fish into a high-protein fish meal which is used primarily as feed supplement in the poultry industry.

Unloading tuna from well of purse seiner in San Diego.

mediate values in 1974 (Kolhonen, 1974).

Market Squid

For many years squid (Fig. 6) have been landed regularly at both San Pedro and Monterey, somewhat independently of the other wetfish species. Squid has maintained an adjusted ex-vessel price of about one cent per pound since 1955. Price peaks occurred in 1952 and 1960 when California production was low. Approximately 90 percent of the U.S. squid production is harvested in California. About half of the annual harvest is canned for export to Mediterranean and Japanese markets.[4] A large portion of the remainder is sold as bait for recreational and commercial fisheries. A smaller portion is marketed through restaurant and retail fish outlets.

TUNAS

The tuna group includes yellowfin tuna (*Thunnus albacares*), skipjack tuna (*Katsuwonus pelamis*), bluefin tuna (*Thunnus thynnus*), albacore (*Thunnus alalunga*), and the Pacific bonito (*Sarda chiliensis*). These species share the same processing facilities, which are different from those used for wetfish processing in that these fish are cooked prior to canning. Albacore are fished along the Pacific coast from Baja California to British Columbia. Bluefin and bonito are important in local southern California fisheries and are fished by both the tuna fleet and the San Pedro wetfish fleet. Yellowfin and skipjack tuna, which are caught in the tropical waters off the west coast of Central America, are processed in southern California, where much of the fleet is based. Since the decline of the sardine fishery in the late 1940's, tuna has dominated the fishing industry in southern California.

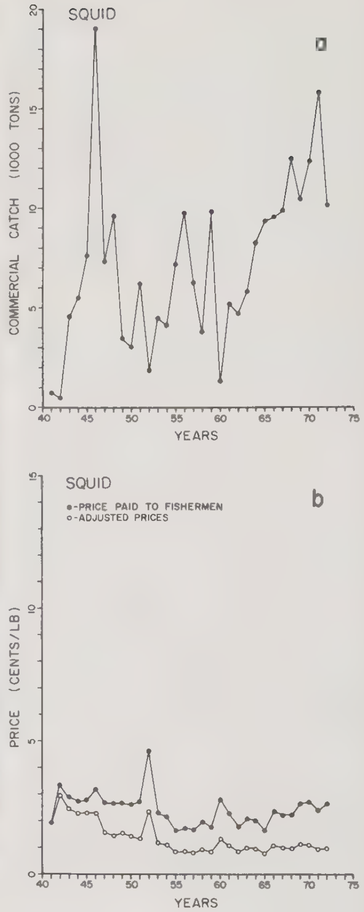

Figure 6.—Annual market squid a) landings in California, and b) average ex-vessel prices paid to fishermen for the years 1941 through 1972.

Ex-vessel price for yellowfin tuna has generally regulated those of skipjack and bluefin tuna. Albacore prices are established separately from the U.S. yellowfin market, but the two are related through the world tuna market. Fluctuations in ex-vessel prices have been influenced by changes in demand, U.S. imports, and domestic production. More detailed summaries of catch and price information for the U.S. tuna industry are reported in the series "Food fish: Market review and outlook" prepared by the Market Research and Services Division of the National Marine Fisheries Service.

The Office of Price Administration of the Federal government during

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[4] Fishery Statistics of the U.S., 1958-71. (Published as Statistical Digests 49-65 by the National Marine Fisheries Service, NOAA.)

World War II set maximum ex-vessel prices and wholesale prices of canned tuna. Generally, supplies were low and prices were high. During the postwar inflationary period, ex-vessel prices jumped to unprecedented levels. These high prices encouraged fishing and increased landings. The expansion of the Japanese high-seas tuna fleet in the mid-1950's had a major impact on the U.S. tuna industry. Imports increased supplies of raw tuna, thereby depressing domestic ex-vessel prices. To market the greater supplies, the canning industry expanded its advertising and merchandising campaigns. These events contributed to the development of a worldwide tuna market in the 1960's.

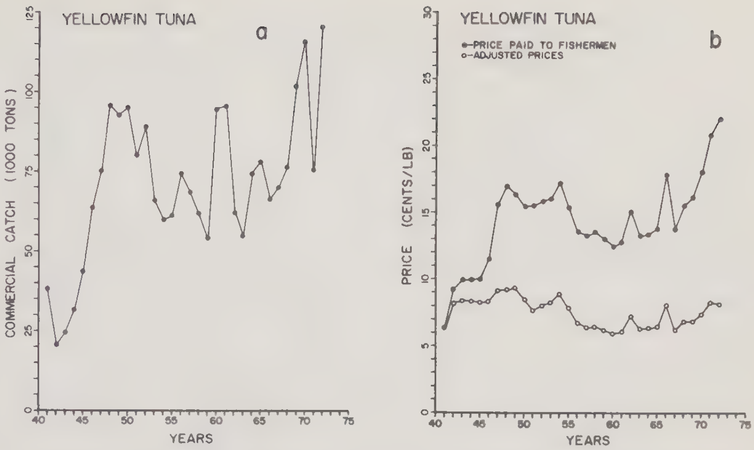

Figure 7.—Annual yellowfin tuna a) landings in California, and b) average ex-vessel prices paid to fishermen for the years 1941 through 1972.

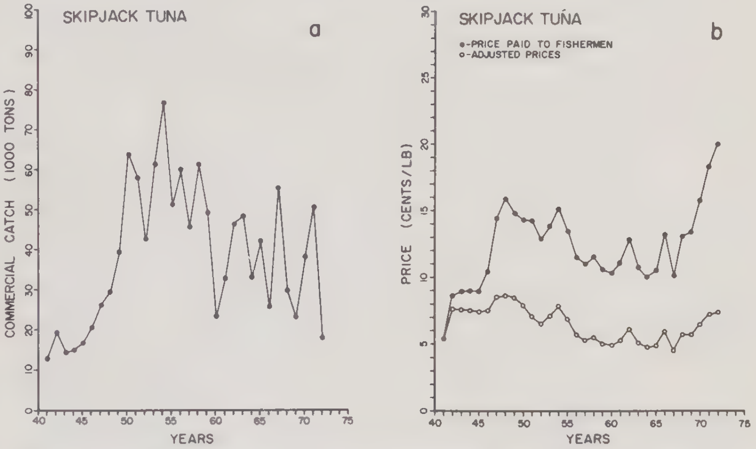

Figure 8.—Annual skipjack tuna a) landings in California, and b) average ex-vessel prices paid to fishermen for the years 1941 through 1972.

Yellowfin, Skipjack, and Bluefin Tunas

Historically, the U.S. tuna fishery has been based in southern California. Tuna landings in California, including foreign shipments, increased substantially in the late 1940's as the sardine harvest declined. California landings of raw tuna and the pack of canned tuna for all species have been relatively stable since 1950, while the total U.S. pack has generally increased over the years to the point that the 1970 pack more than doubled the 1950 pack. U.S. tuna deliveries to Puerto Rico and tuna imports from the Japanese fishery to American Samoa account for the major portion of this increase.

The general downward trend in adjusted ex-vessel prices from the postwar period reflect the increasing production of canned tuna[5]. Heavy domestic production and Japanese imports in 1950 resulted in a large inventory carryover and lower prices in 1951. Successful marketing campaigns in the subsequent years helped reduce canners' inventories, and ex-vessel prices increased. Prior to 1953, seasonal tuna prices were negotiated between major canners and leading boat owners, but beginning in 1953, the American Tunaboat Association collectively negotiated the tuna sales. These negotiations resulted in the peak prices of 1954. In the years following, this system became ineffective owing to the increased supplies of imported tuna, and average prices gradually declined. Imports of frozen tuna doubled between 1957 and 1959. This jump coincides with low prices of 1959 and 1960. The 1962 price buildup began in the latter half of 1961, and the case pack reached an all-time high for California in 1962. With supplies high, ex-vessel prices began dropping in the latter half of 1962. The decline continued into 1963 with large inventory carryovers. These prices continued until the beginning of 1966 when U.S. and import supplies reached an all-time January low. As a result, ex-vessel prices soared to record levels in the first half of 1966. Imports and domestic production of tuna, particularly skipjack, increased to the point that ex-vessel prices plunged again in 1967. This price drop provided the stimulus that unified boat owners and organized the "empty boat" auction under the American Tuna Sales Association. This auction system has continued to the present time. Ex-vessel prices have increased since 1968, even under increases in the annual production of tuna.

Ex-vessel prices for skipjack and bluefin tuna have almost always been less than those for yellowfin (Figs. 7, 8, 9). Prior to 1952, skipjack prices were routinely 1 cent per pound ($20/ton) less and bluefin were 0.5 cent per pound ($10/ton) less. Since then the price differential for skipjack has averaged about 2 cents per pound ($40/ton). It increased to as much as 4 cents in 1966.

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[5] The information source for this paragraph is the series of "Pacific Fisherman Yearbooks," 1951-1967.

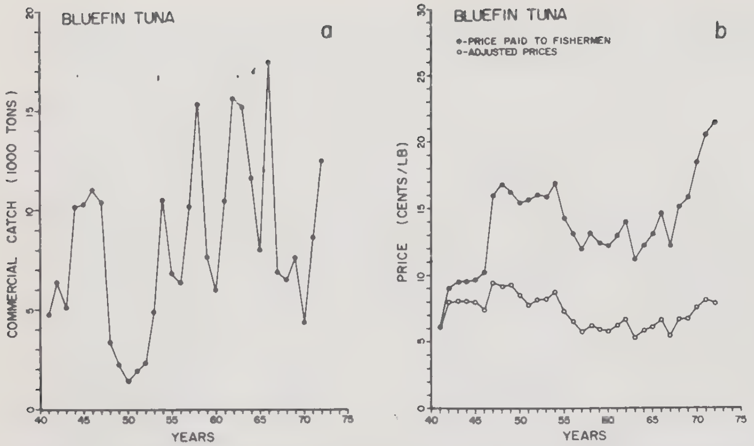

Figure 9.—Annual bluefin tuna a) landings in California, and b) average ex-vessel prices paid to fishermen for the years 1941 through 1972.

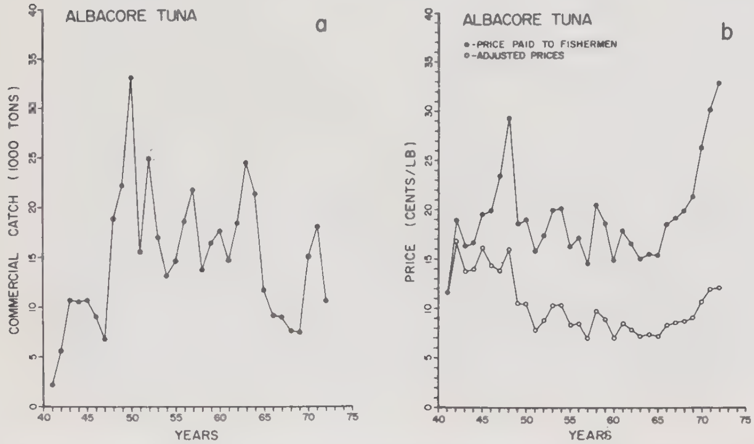

Figure 10.—Annual albacore tuna a) landings in California, and b) average ex-vessel prices paid to fishermen at the buying stations for the years 1941 through 1972.

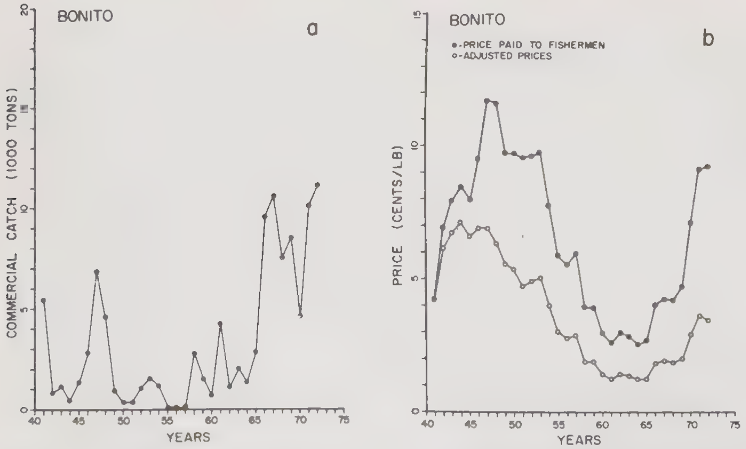

Figure 11.—Annual Pacific bonito a) landings in California, and b) average ex-vessel prices paid to fishermen for the years 1941 through 1972.

The bluefin price differential increased to 2 cents per pound in 1961 and reached a maximum in 1966-67. Since 1968, skipjack price differential has declined from 2.5 to 1.5 cents per pound and the bluefin differential has remained 1 cent per pound.

Albacore

The albacore (Fig. 10) fishery occurs off the Pacific coast from Baja California to British Columbia. Landings in southern California were the major portion of the domestic catch for the years 1948 through 1964. For the other years the major portion was landed in the Pacific Northwest. The geographic location of the fishery has little influence on price trends.

Ex-vessel prices jumped to unprecedented levels during the postwar inflationary period. These high prices encouraged fishing. Good fishing in California in 1950 resulted in a large carryover into 1951, and as the Pacific Northwest fishery did not develop in 1951, canneries imported frozen tuna from Japan to keep the processing plants in operation. As a result of the large inventories, prices declined. During the following 3 years, an expanding market assisted recovery of the ex-vessel prices.

A large-scale surge of imported albacore, both frozen and canned in brine, began in 1955. Domestic albacore prices dropped in response to the increased supplies. The downward price trend continued until 1966. Major price drops of 1955, 1957, 1960, and 1962 correspond to years with increased imports. In recent years imports of frozen albacore have accounted for as much as 75 percent of the white meat tuna canned domestically.

After 1967, a price trend reversal occurred. The increase is due to the general increase in ex-vessel price of all fishery resources, unified collective bargaining by the Western Fishboat Owners Association, continual advertisement and sales promotion, and increased demand for Japanese tuna by other world markets.

Pacific Bonito

Prior to the mid-1950's the major portion of the bonito (Fig. 11) catch was taken in waters off Baja California by purse seiners. Many of these were tunaboats topping off their load with bonito and yellowtail on their return to southern California ports. During this time, ex-vessel prices reflected those of the other tuna species. As tuna landings increased in the late 1940's, adjusted prices for the less desirable bonito declined. In 1952 tariffs on canned bonito and yellowtail were reduced from 21 percent ad valorem to 15 percent (Pacific Fisherman, 1952, p. 167). Imports from Peru and Chile increased as a result. These added imports tended to further reduce the price paid to southern California fishermen. As a result of the necessity to market the increasing supplies of the more widely accepted white and light meat tuna products in the early 1950's, the industry ceased marketing canned products of the tuna-like species, bonito and yellowtail, and the canned bonito market was taken over by the Peruvian product. Domestic ex-vessel prices declined to a level comparable to that of the wetfishes, and California landings became negligible. Later, a local California purse-seine fishery developed in 1958, probably in response to increased availability in southern California waters. At these low ex-vessel prices the U.S. product was probably competitive with the Peruvian products. As the anchoveta fishery developed in the early 1960's, Peruvian production of canned bonito declined[6]. U.S. imports of Peruvian bonito for 1965-67 dropped to 20 percent of the 1951-59 average and for 1968-70 to 5 percent[7]. In response to price increases, the U.S. fishery expanded considerably to supply the market vacated by the Peruvian bonito. Prices jumped again in 1970 when the availability of bonito off California was down from earlier years. In recent years, tariffs on imported bonito have been reduced twice, from 15 percent ad valorem to 12 percent in January 1969 and to 7.5 percent in January 1972 (Economic Research Laboratory 1973). This has encouraged the importation of Peruvian bonito to 1965-67 levels but has not greatly influenced U.S. prices.

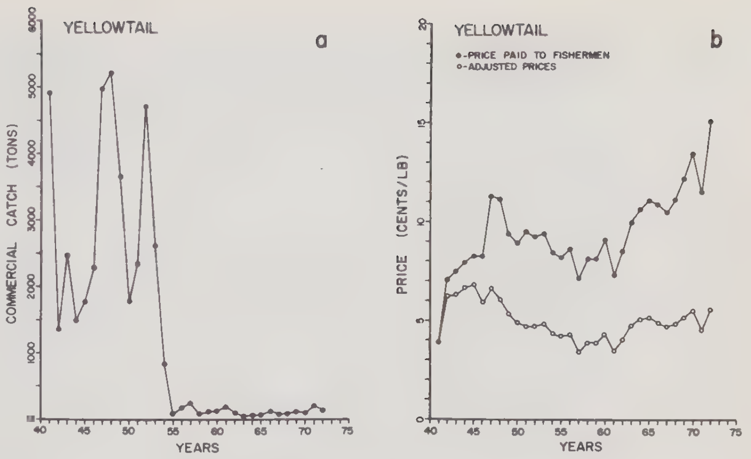

Figure 12.—Annual California yellowtail a) landings in California, and b) average ex-vessel prices paid to fishermen for the years 1941 through 1972.

MARKET FISH

The "market fish" group is composed of some of the large predatory coastal fishes: yellowtail (*Seriola dorsalis*), white seabass (*Cynoscion nobilis*), California barracuda (*Sphyraena argentea*), and the rockfishes (*Sebastes* spp.). These species tend to be sold fresh or occasionally frozen and are utilized locally in southern California, fetching high prices but with relatively small volume. Yellowtail and California barracuda are highly migratory, with the main center of population occurring in Baja California waters. The market species are harvested by a southern California fleet employing gill nets and a variety of hook-and-line gear. Local availability of migratory species in the late spring and summer allows most vessels to concentrate their activities in the southern California area, while in the winter months many boats venture far down the Baja California coast. The years 1957-60 were characterized by extraordinarily warm waters in California, and many migratory species appeared to have shifted their population centers northward. This is reflected in the large local southern California catches of these species. Prices of migratory market species for these years were generally depressed by oversupply.

Yellowtail

The yellowtail (Fig. 12) could be considered a member of the "tuna" group as well as the market fish group. While not a true tuna (family Scombridae) but a jack (family Carangidae), the yellowtail has contributed to the tuna fisheries of California. Prior to 1954, a considerable fishery existed with most fish

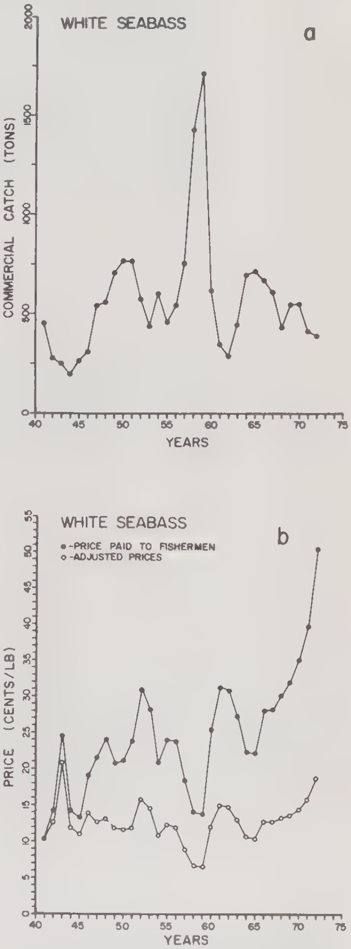

Figure 13.—Annual white seabass a) landings in California, and b) average ex-vessel prices paid to fishermen for the years 1941 through 1972.

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[6] FAO Yearbook of Fishery Statistics, 1959-73.
[7] Fishery Statistics of the U.S., 1951-70. (Published as Statistical Digests 30-64 by the National Marine Fisheries Service, NOAA.)

caught in waters off Baja California. In the mid-1950's, the industry ceased canning and marketing yellowtail to concentrate on the more profitable tuna products (Baxter, 1960). Subsequently yellowtail became a market fish, being sold primarily as fresh fish, and being landed by the market fleet rather than the tuna fleet. The price has remained rather stable since 1950, showing some tendency to decrease with increases in annual landings for 1957, 1961, and 1971.

White Seabass

The price of white seabass (Fig. 13) has been quite sensitive to annual fluctuations in catch, but has oscillated about an adjusted price of about 12.5 cents per pound with no apparent trend except for the increase in the most recent years. This is one of the highest prices paid for any fish species. It is esteemed for its flavor and has a well-established market demand. Price is for fish gutted with heads on rather than in the round, as is the case for all other species discussed.

California Barracuda

The apparent abundance of barracuda (Fig. 14) has declined substantially since the late 1940's, although commercial catches may overstate this decline since commercial landings are limited to large fish. The party-boat sport catch remained fairly constant in numbers of fish landed (except for the warmwater years), although average size has decreased. The price paid to commercial fishermen has remained remarkably constant and shown little tendency to rise as catches declined. However, the price did fall when fish were temporarily plentiful in the late 1950's. The recent price increase is characteristic of the general price increase of fishery products and is not necessarily explained by lower production of commercial fish.

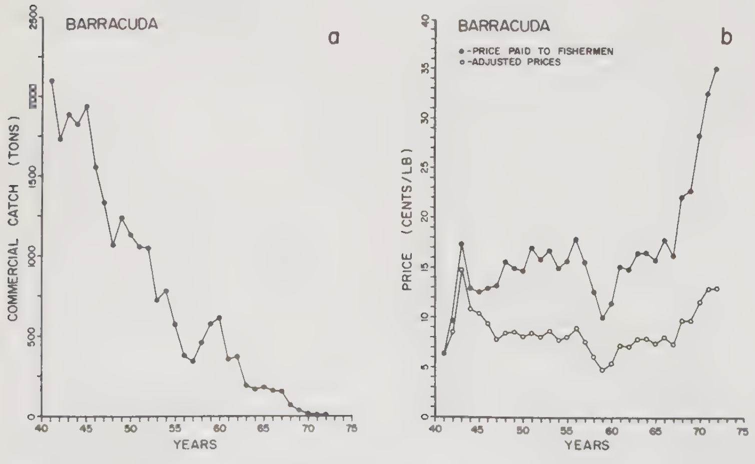

Figure 14.—Annual California barracuda a) landings in California, and b) average ex-vessel prices paid to fishermen for the years 1941 through 1972.

Rockfish

The general category of rockfish (Fig. 15) includes many species of the genus *Sebastes*. Depending on the palatability of the species, rockfish are sold either as animal food or as market fish for a higher price (Miller and Hardwick, 1973). The trawl fishery in northern and central California, including Santa Barbara county, lands about 90 percent of the total California harvest. It supplies both the market and animal food industries. The gill-net and hook-and-line fisheries south of Santa Barbara primarily land market species. In order to examine the price history for market species in southern California, only the time series for the smaller southern fishery were included in Figure 15. On the other hand, the northern harvest probably has more impact on the price of market species than the southern fishery, which has gradually increased production since the late 1940's. Prior to 1959, the adjusted price shows a slight downward trend to a low of 4.7 cents per pound in 1958, the year of maximum rockfish production in California. Since that time, prices have gradually increased with only slight fluctuations as the total catch declined. Increased landings in the most recent years may have dampened the price rise which is apparent in other market species.

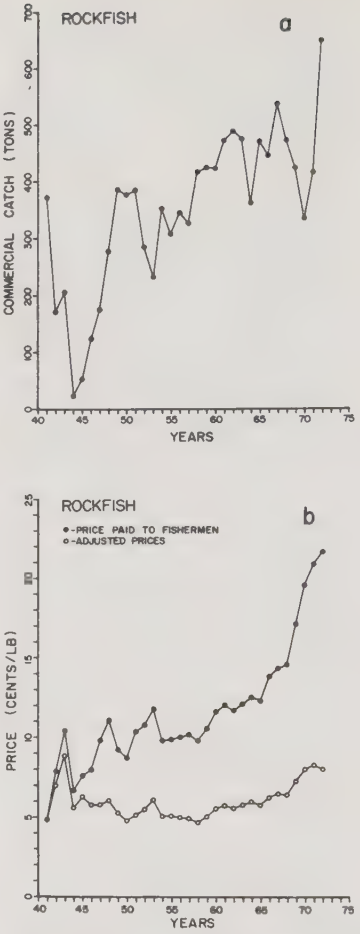

Figure 15.—Annual rockfish a) landings in Los Angeles and San Diego areas, and b) average ex-vessel prices paid to fishermen for the years 1941 through 1972.

SUMMARY

Ex-vessel prices have been deflated by the wholesale price index to account for inflation, particularly during the post-World War II and recent periods. Adjusted prices for all stocks in the 1950's and 1960's are generally lower than those of the 1940's, except for the depleted sardine and Pacific mackerel stocks. In recent years, the price for most species, except anchovy and squid, have increased at a rate somewhat greater than inflation.

Filleting rockfish in Santa Barbara for the fresh fish market. Photo courtesy of biologist Jack W. Schott, California Department of Fish and Game.

The harvest of wetfish species has been primarily influenced by the decline in the sardine stock followed by the Pacific mackerel stock. Prices have been influenced by resource use, i.e., canning, bait, fresh market, or meal reduction. The wetfish species generally have the lowest ex-vessel price of the three groups.

Total California landings of the tuna group have not changed greatly since the early 1950's. California prices have been primarily influenced by the increased world production of tuna and foreign imports of frozen tuna into the United States. Consumer demand in the mid-1950's was less than production and prices tended to sag. In recent years, worldwide consumer demand has increased and prices have increased. Since the collapse of the sardine stocks, the tuna group has dominated the commercial fishing industry in California.

The market fish group, harvested by a nearshore gill-net and hook-and-line fishery, supplies local demand for fresh fish. Except for the rockfish category, most of the species are migratory along the Baja California and southern California coastline. Prices for this group have been relatively constant except during periods of increased availability. Prices are similar to the tuna group but the catches are considerably less.

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ENVIRONMENTAL FACTORS AFFECTING STRESS AND MORTALITY OF THE HAWAIIAN ANCHOVY IN CAPTIVITY

by

Jeannette Whipple Struhsaker
Wayne J. Baldwin
Garth I. Murphy

Report on the Sea Grant project, Further Exploration and Development of a Tuna Live Bait Resource (R/6a-01); Wayne J. Baldwin, Principal Investigator; Sea Grant Years 03 - 04.

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INTRODUCTION

Stolephorus purpureus (Hawaiian anchovy or nehu) is the predominant baitfish used in the Hawaiian skipjack tuna *(Euthynnus pelamis)* fishery. The nehu is small, readily loses scales, and is susceptible to shock and subsequent osmoregulatory stress and most of its mortality originates from injuries sustained during capture and handling. The capture and holding of nehu in vessel bait wells have been problems for some time, as bait wells currently in use on most tuna vessels are inadequate for optimal survival of nehu. Average baitfish mortalities following capture often reach approximately 25 percent per day or more (Brock and Uchida, 1968).

The baitfish problem is twofold: (1) time spent seeking and capturing bait decreases time spent tuna fishing and (2) high bait well mortality shortens fishing time. These and other operational aspects of the Hawaiian live bait fishery are extensively described by Brock and Uchida (1968), who emphasize the development of a means of reducing baitfish mortality to increase fishing efficiency as a profitable research goal.

The objective of this research is the reduction of nehu mortality. This work is an extension of studies by Brock and Takata (1955) which demonstrated that reduced salinity and increased aeration significantly reduce nehu mortality in bait wells. In addition to aeration and salinity, the effects of pure oxygen, temperature, current, light, tank color, recirculated reduced salinity, buffers, protein skimmer, density, food, disease, and predation were also examined.

Note: All tables have been omitted from this report, although references to them have been retained. Except for Table 24, which summarizes the correlation matrix of 34 laboratory variables, all tables are available on request from the Hawaii Institute of Marine Biology, P.O. Box 1346, Kaneohe, Hawaii 96744. A listing of the tables can be found in the Appendix to this report.

Other studies of nehu include those of Hiatt (1951) on food and feeding habits; Tester (1951, 1955) on distribution of eggs and larvae in Kaneohe Bay; Au (1965) on distribution of eggs and larvae in Pearl Harbor; Yamashita (1951) on larval development; Burdick (1969) on larval feeding; Bachman (1963) on aspects of population dynamics; and Pritchard (1955) on lethal oxygen level. The National Marine Fisheries Service, Honolulu Laboratory also conducted several studies on nehu, the most recent being experimentation with a baitfish-holding facility in Kaneohe Bay ([U.S.] Bureau of Commercial Fisheries, 1969). Many of these studies and others are summarized in a synopsis prepared by Nakamura (1965).

The research program was organized into two phases: (1) a study of factors affecting survival and methods to increase survival and (2) application of the experimental results. The study under the first phase was made (a) during bait capture and transfer to bait wells, (b) in 180-gal experimental laboratory tanks, (c) in 1,000-gal bait wells on an experimental barge, and (d) in vessel bait wells at sea. The experimental results were applied (a) to the designing and testing of an improved, experimental bait well and (b) to providing extension service to the tuna industry. This report encompasses the results of capture, transfer, and laboratory and barge experiments. Results of the remaining factors are given by Baldwin et al. (1972) and Baldwin (1973).

By suggesting small and inexpensive improvements of bait wells on existing vessels and also by aiding in the designing of new vessel bait-holding facilities it is hoped that this research will eventually benefit the tuna industry.

METHODS: BAIT CAPTURE

The equipment and general procedures for capture of bait and for barge and laboratory experiments are given below. Experimental modifications for individual barge and laboratory experiments are described where applicable in the "results" section.

Capture and Transport Equipment

Barge

An experimental barge was designed to test the effects of improved bait-handling techniques on the survival of nehu (Plate 1). Two bait wells with movable gates were provided so that bait could swim from the capture net into the wells with minimum handling. This procedure eliminated the bucketing process which usually resulted in considerable handling injury.

Plate 1. The nehu barge anchored near the west side of Coconut Island, Kaneohe Bay, Oahu. The barge is 11.0 m by 5.5 m (36 x 18 ft) and is equipped with two 3,784-liter (1,000-gal) bait wells; a laboratory containing a desk, sink, refrigerator, and two bunks; and a generator room with two small gasoline generators. The two long poles or "outriggers" at left support the lift net and are used to raise and lower the net during night baiting.

The design of the bait wells was modified throughout the experimental period. These modifications included two current standpipes and a seawater pump (Plate 2), a protein skimmer (Plate 3), an oxygen system, and a green gel-coat, resin-painted interior.

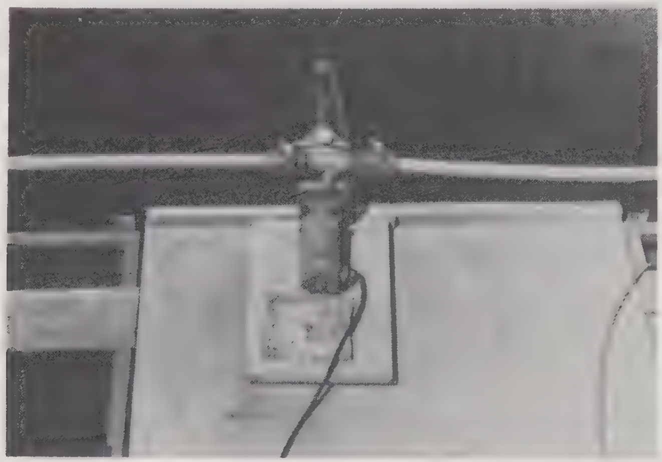

Plate 2. A 1-hp Jaccuzi pump set up on the nehu barge. The seawater intake hose is at top center and extends to about 2.4 m (8 ft) below the surface. The two valves and PVC pipes lead to both bait wells discharging seawater through a perforated current standpipe located in each well.

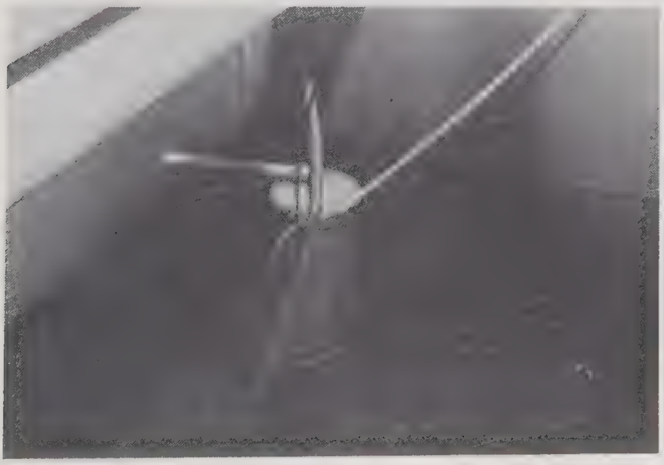

Plate 3. One of the nehu barge 3,784-liter (1,000-gal) bait wells. The removable gate through which the nehu enter the bait well is at the lower left. A large 25.4-cm (10-in) ID protein skimmer is suspended in one corner during an experiment. The horizontal PVC pipe leading to the left from the top of the skimmer discharges the concentrated foam outside the bait well. The hoses are for oxygen, seawater, and compressed air.

Bait receiver

A small barge was designed and built specifically to function as a bait receiver (Plate 4). It was constructed of 1/4-inch marine plywood with ten screened openings to provide adequate water circulation. A removable gate through which the nehu entered from the bait seine was added to each side of the receiver. The main receiver compartment in which nehu were confined measured 1.8 m by 1.2 m with a depth of 0.7 m (70 in x 48 in x 29 in). When submerged to a depth of 0.6 m (22 in) it contained 1,140 liters (302 gal) of seawater excluding the 0.9-m (36-in) bow compartment. Several large weights were placed in the floating bait receiver to sink it to the desired depth. A portable oxygen cylinder and stone were used to maintain oxygen in the receiver during transport of bait (Plates 5 and 6).

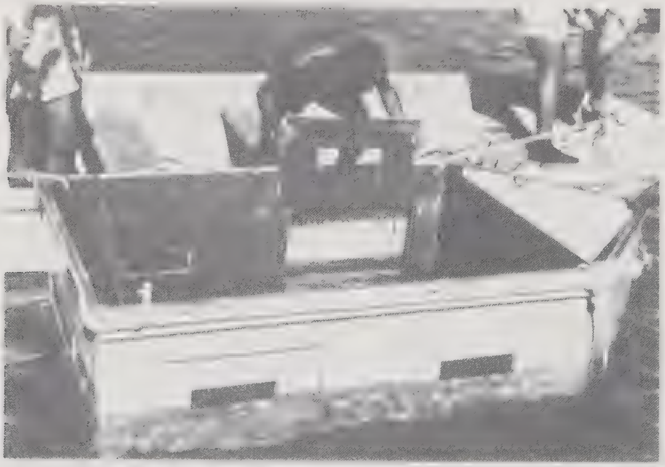

Plate 4. Nehu bait receiver being readied for moving nehu. The gate through which the nehu were forced to swim is being removed. The screened openings allow seawater to circulate in the bait receiver during transport. Two heavy weights are placed on the bottom of the receiver to sink it to a point just above the top of the closed gates.

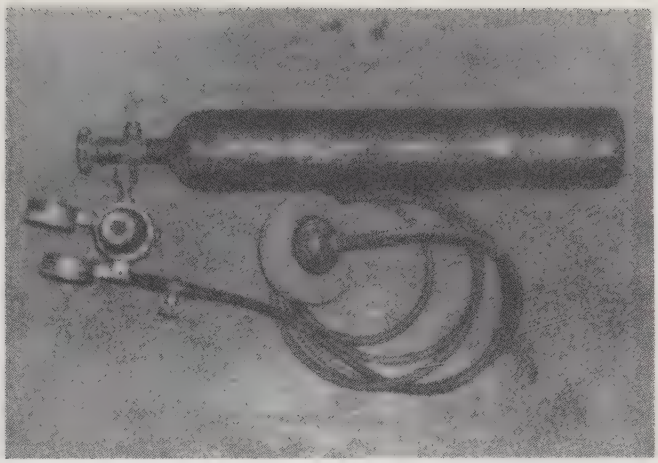

Plate 5. The portable oxygen unit used during nehu transport from the capture area to the laboratory. The unit consists of a 0.6-m^3 (22-ft^3) oxygen cylinder, pressure regulator and gauges, hose, and oxygen stone.

Plate 6. A concentration of nehu enclosed within the plywood bait receiver. The white cloud at center is pure oxygen being released from the oxygen stone placed on the bottom of the receiver.

Seines for day capture

Two bait seines were constructed of 1/8-inch bar mesh for daytime capture of nehu. A 110 m by 6 m (360 ft x 20 ft) deep seine similar to but shorter than commercial seines was constructed. This net was designed for collecting nehu in areas of 1.5 m (5 ft) or more in depth. A small 46-m seine measuring 3.7 m deep at the center and tapering to 1.8 m at the wings (150 ft x 12 ft x 6 ft) was designed for use in shallower areas to reduce injuries to nehu captured in large nets.

Net for night capture

A net was constructed using a 1/8-inch square mesh on the bottom and with 3/16-inch mesh on each side. It was approximately 8.2 m long by 6.1 m wide by 6.1 m deep (27 ft x 20 ft x 20 ft). In a lowered position the net was similar to the net described and illustrated by Brock and Takata (1955).

Night Capture Procedures

Capture area

Nehu were captured at night with lights suspended from the experimental barge anchored about 6.1 m (20 ft) off the southwest shore of Coconut Island, Kaneohe Bay, Oahu (Plate 1). The depth of the water in front of the barge was approximately 9 to 10 m (30 ft).

Capture technique

Around sunset (between the hours of 1730 and 1900) three white floodlights (100 watts each) attached to the barge were switched on and the sides of the net lowered. Another light (250 or 300 watts, white incandescent, suspended from a long pole, was submerged approximately 2.5 m (8 ft) to the center of the net area.

Periodically throughout the night, the water surrounding the center submerged light was examined for nehu. When sufficient nehu were detected, the submerged light was dimmed to 50 or 60 watts to consolidate the fish around the light. The edges of the net were then raised surrounding the school. However, if nehu were not observed during the night, the net was raised at dawn.

Environmental data

From April 1967 to June 1970, 78 net sets were made at night from the barge to obtain bait for experiments. Major environmental factors were measured during all-night capture experiments regardless of capture success. Attempts to obtain bait were usually correlated with need for experimental nehu and not with determining appropriate times for capturing night bait. Data obtained were not temporally systematic. However, data on major environmental variables were recorded, in hope that they might reveal opportune times for night baiting. Records were made of the following variables for the last 67 sets: approximate number of buckets of nehu captured, date, time, moon phase, time of tide, range of tide, weather (rainfall, wave action, wind speed), turbidity, temperature, salinity, and presence of predators.

Loading and transport

According to experimental plan, the captured nehu were made to either (1) swim from the lift net through the gates into the barge wells (Plate 3) or (2) swim from the net into the bait receiver and then were transported to laboratory tanks on the opposite side of Coconut Island. Further details of bait transport over longer distances follow.

Day Capture Procedures

Capture of nehu during daylight hours followed essentially the same method described by June (1951). Since 1951 there has been little change in bait-seining techniques except for more general use of modern outboard motors and improved nets made of synthetic materials.

Capture areas

Nehu were seined primarily in the southern sector of Kaneohe Bay (Figure 1). Other seining areas exist along the northern shores of the bay but these were not utilized because of their extreme distance from Coconut Island.

The most consistent supply of nehu occurred along the southeast shoreline adjacent to the Nuupia-Halekou pond complex and well within a restricted zone extending 457 m (500 yd) offshore from the Mokapu Peninsula (U.S. Coast and Geodetic Survey Chart No. 4143). Normally, commercial aku fishermen are not permitted in this area to seine nehu without clearance from military authorities. This policy no doubt contributed to successful seining. Of the 34 laboratory and barge experiments in which day-captured nehu were used, 30 were conducted with nehu captured within or near this area.

The topography of this area is representative of other nehu-seining areas in Kaneohe Bay. The water is usually murky and the inshore zone frequently exposed during low tides. The bottom contour gradually slopes toward deeper water where there is a steep drop-off caused either by a coral shelf or from bottom dredging. The bottom is soft mud or soft mud and sand mixed with coral rubble. With the exception of one seining

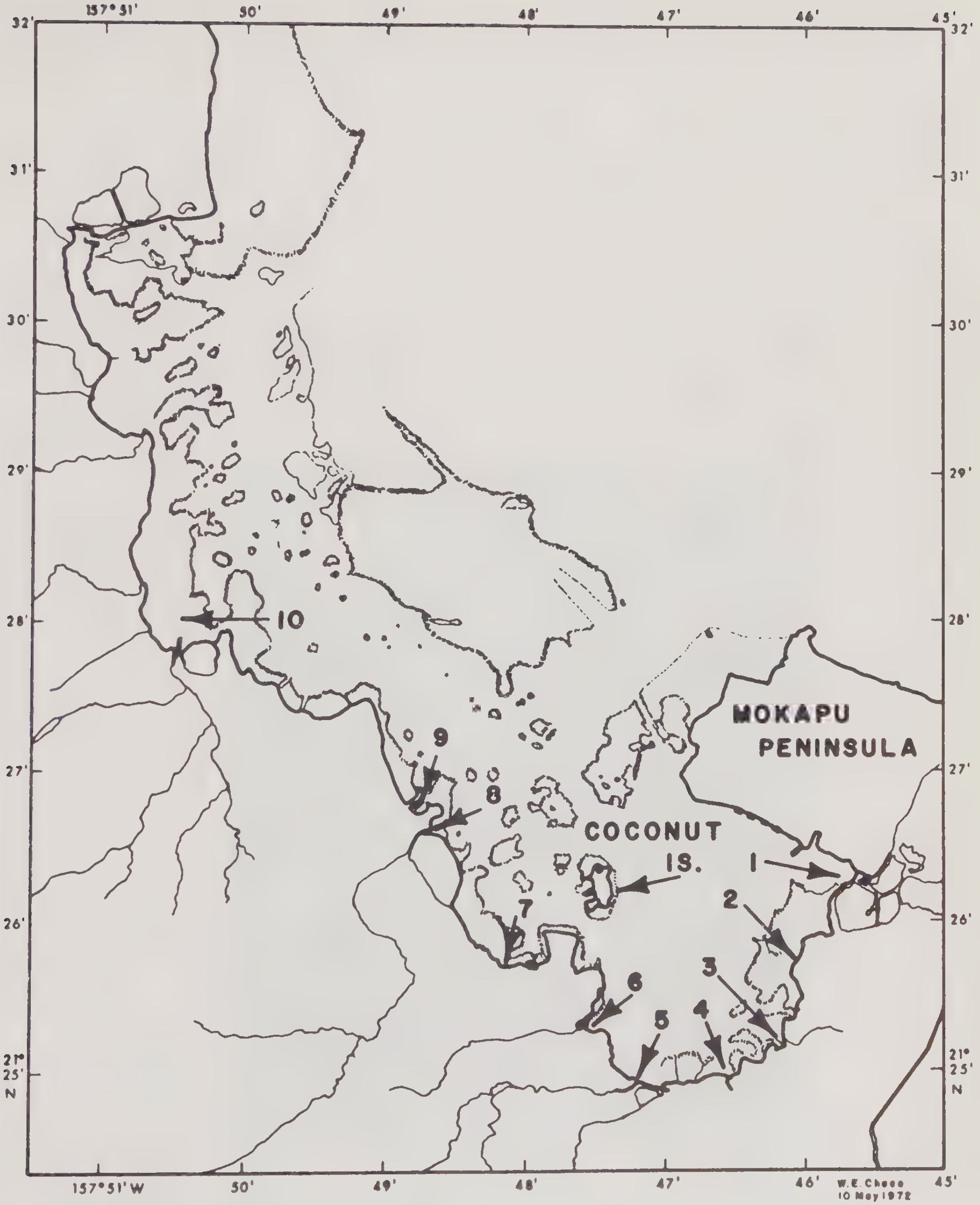

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Figure 1. Map of Kaneohe Bay, Oahu showing collection localities for day-captured nehu from 1967 to 1970: (1) Nuupia Pond area, (2) Malae, (3) Keaalu, (4) Kokokahi, (5) Kaneohe and Kawa Streams, (6) Keaahala Stream, (7) Alii Shores, (8) Heeia Stream, (9) Heeia Pier, and (10) Kahaluu.

collection, all successful captures were made in the inshore, mud-bottom habitats having a maximum depth of 1.5 to 1.8 m (5 to 6 ft).

Seining

The bait-seining operation required two skiffs: one for setting the bait seine and another for handling the bait receiver. After the concentration of nehu was located and the net skiff maneuvered into position, one person jumped into the water holding one end of the net. The net skiff and seine were then rapidly circled around the nehu and the ends of the seine were brought together to close the net completely. While one person remained in the water to keep the net closed, others slowly pulled the net in toward the skiff (Plate 7) until a large pocket remained that enclosed the nehu. Setting and closing the 46-m seine required about 10 minutes; the 110-m net took 15 to 20 minutes. It was only occasionally necessary to set the entire length of the larger net.

Plate 7. The 46 m by 3.7 m (150 ft by 12 ft) nehu bait seine being closed after setting around a school of nehu. The person in the water at center is keeping the net closed to prevent nehu from escaping.

During the final moments of closing the bait seine, the bait receiver was maneuvered into position with the nearer gate removed and the seine attached onto four hooks around the open gate. By gradually closing the pocket of the seine, nehu were forced to swim into the bait receiver. After a suitable number of nehu had been forced inside, the gate was closed, the net unhooked, and the portable oxygen unit turned on (Plates 5 and 6). Then excess nehu were released and the seine loaded into the net skiff which in turn was maneuvered alongside the bait receiver and secured (Plate 8).

Plate 8. The bait receiver being towed to the laboratory with a collection of nehu. The receiver is secured between the two skiffs and slowly towed through the water at approximately 2 mph while adding pure oxygen.

Transport

The receiver was pulled through the water at a speed of approximately 2 mph to provide water circulation through screened openings while keeping agitation inside to a minimum. On days of strong winds no attempt was made to capture and transport nehu in this manner since injuries and subsequent heavy mortalities increased during these conditions.

Depending upon the collection locality and the distance to Coconut Island, transporting the bait receiver took from 20 to 90 minutes. During this time oxygen was continuously added and dead and critically injured nehu, along with predators and other unwanted fishes or invertebrates, were removed by hand net. Nehu were immediately removed from the bait receiver after reaching the laboratory. Transfer time by bucket from the bait receiver to laboratory tanks usually took less than 5 minutes. Swimming or bucketing nehu into barge bait wells required 5 minutes or less.

METHODS: LABORATORY AND BARGE EXPERIMENTS

Equipment

Barge wells

The two barge bait wells held approximately 1,000 gal of seawater and were gradually modified throughout the experimental period as previously described (Plates 1 to 3). The final design provided either open or closed circulation, pure oxygen, and current. The interior was painted with green gel-coat resin and a protein skimmer was added for the removal of mucus, scales, and organic debris.

Laboratory tanks

Some of the laboratory experimental tanks are shown in Plates 9 and 10. Altogether there were ten experimental tanks; five on each side of the laboratory. The arrangement was designed to provide five simultaneous experimental situations, each with a replicate. The tank design is that of Alderdice et al. (1966); tanks were purchased from Vancouver Plastics, Vancouver, B.C., Canada. The oval tanks have slightly sloping walls and a center drain and are finished with green-blue, gel-coat resin. They contain approximately 680 liters (180 gal) when the water level is 4 inches below the top.

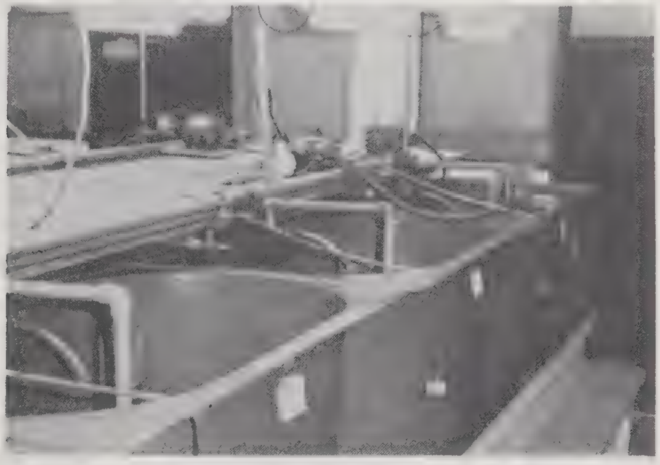


Plate 9. Several of the 680-liter (180-gal) fiberglass tanks as they were set up in the laboratory. Ten of these tanks were arranged in two rows and were provided with seawater, compressed air, pure oxygen, overhead lighting, and current standpipe. For full description of tanks see Alderdice et al. (1966).

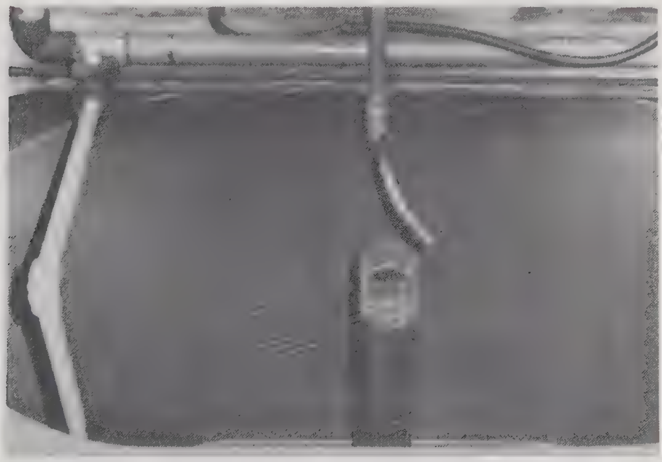


Plate 10. The interior of one of the laboratory tanks. The inside was finished with a green gel-coat resin and had round ends, sloping sides, and a double standpipe central drain. The perforated current standpipe is at left.

The tanks were gradually modified throughout the experimental period. They were supplied with a water-inflow valve, current standpipe, air outlet, oxygen outlet, oxygen releaser, and protein skimmer. The oxygen equipment is shown in Plates 11 and 12; the protein skimmer in Plates 13 and 14. The oxygen releaser described by Baldwin (1970) was designed to emit small bubbles of oxygen into seawater with a maximum degree of saturation and minimum oxygen loss; it was adapted for use in laboratory tanks. Water was supplied from Kaneohe Bay, pumped to storage tanks through PVC lines, and fed to the laboratory by gravity through Cuno filters (Plate 15).

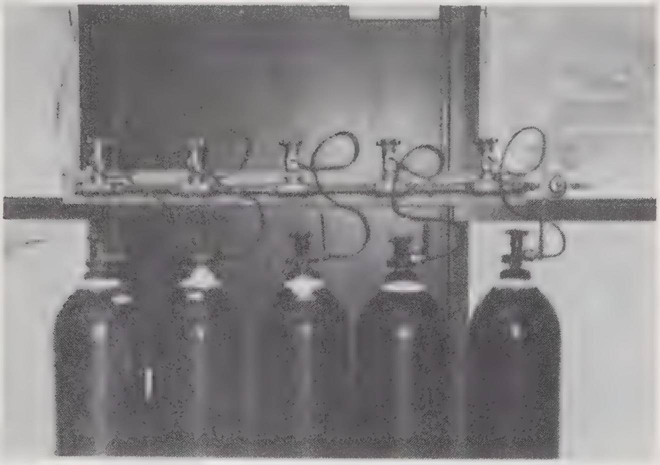


Plate 11. Five 6.8-m^3 (240-ft^3) industrial oxygen cylinders mounted against one wall of the laboratory. Normally, only two cylinders were in use at any given time; the additional three are reserves. The oxygen manifold with the five selector valves is mounted over the tanks with pressure regulator and gages and oxygen delivery hose at right.

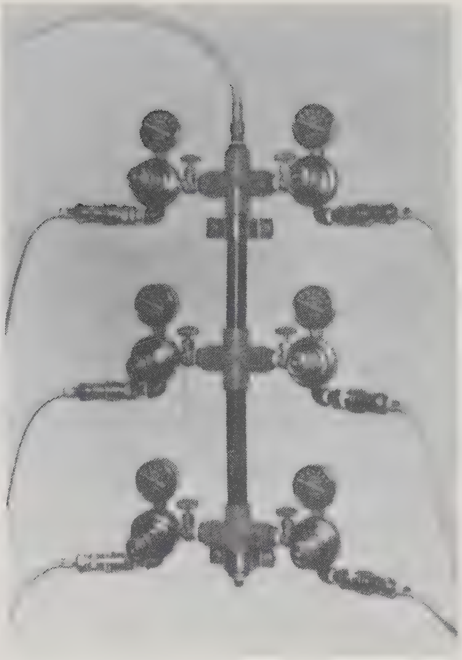


Plate 12. A low pressure PVC oxygen manifold used for metering the oxygen to individual releasers during experiments. The hose at top connects to the large oxygen cylinders (Plate 11). The smaller transparent hoses lead to individual stones and have quick-release, snap-on stainless steel fittings.

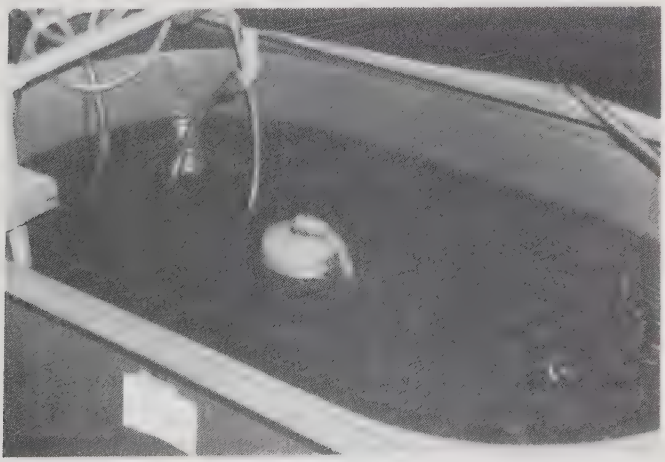


Plate 13. A 7.6-cm (3-in) ID laboratory protein skimmer secured to the center drain standpipe. The hoses at left are for pure oxygen, compressed air, and seawater circulation to the protein skimmer. The current standpipe is at the far left.

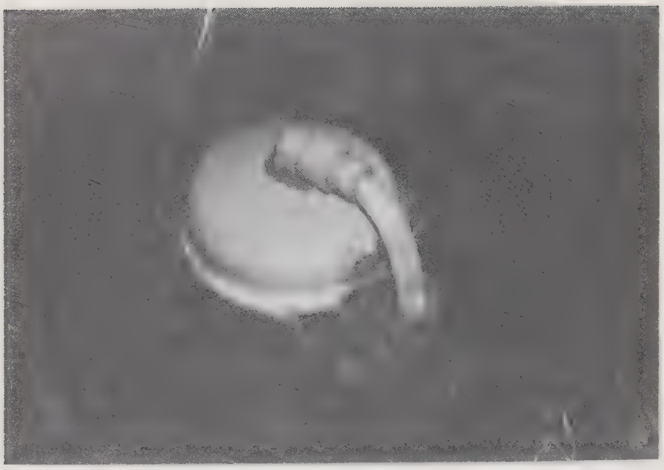


Plate 14. The 7.6-cm (3-in) ID laboratory protein skimmer in operation during an experiment. Seawater is moved through the vertical skimmer while air is bubbled from the bottom. The foam is concentrated at the top of the skimmer and discharged from the laboratory tank through the transparent hose that empties into the center drain.

Plate 15. Two Cuno filters used for filtering seawater for laboratory experiments. Seawater passes up the central PVC pipe through the two filters and to the two banks of fiberglass tanks. The filter elements were changed twice daily to ensure a continuous, steady flow of seawater.

Number of nehu per bucket

A common unit used by Hawaiian fishermen to measure nehu is the bucket. Obviously, the number and weight of nehu in one bucket vary. For purposes of this discussion, one bucket of bait is defined as containing an average of 2,700 fish and weighing approximately 1,300 to 1,900 gm (3 to 4 lb) with a mean weight of 1,700 gm (3-3/4 lb). Experimental containers were 5 to 6-gal stainless steel buckets filled approximately one-half to three-quarters full with water and fish (Plate 16). Usually, local commercial fishermen concentrate the nehu in buckets to as much as 2,700 to 3,600 gm (6 to 8 lb). Reducing the number of fish per bucket in proportion to the amount of seawater reduces injuries.

Order of filling tanks or wells

Initially, it appeared that the number of nehu per bucket varied as tanks were filled, with later buckets containing fewer fish. A possibility

Plate 16. A bucket of nehu being emptied into one of the laboratory tanks at the beginning of an experiment. The screened standpipe at left is a double standpipe drain system in which the water is removed from the bottom instead of the top.

of differences in size or condition of fish as tanks were filled also existed. Subsequently, tanks were filled at random to eliminate any variation possibly influencing mortality rates.

Daily Measurement Procedure

Measurement procedures varied with experimental objectives, but a basic procedure was followed throughout the experimental period. Any modification of the procedure is indicated in the "results" section.

Variables were usually measured three times daily. The fish were first observed and their milling direction and other behavior noted. Oxygen (in ppm) was measured with a YSI Model 50 oxygen meter standardized by the Winkler method (Strickland and Parsons, 1968); salinity (in ppt) was measured indirectly with a Goldberg T/C Refractometer (Brix) calibrated to Copenhagen seawater standards; and temperature (in °C) was measured with a laboratory thermometer. Most measurements were accurate to the nearest 0.1 unit. In some experiments measurements of pH were made with a Coleman Model 37A pH meter to the nearest 0.01 unit. Measurement of CO_2 was made according to the indirect method of Strickland and Parsons (1968) to the nearest 0.001 unit.

Following this procedure, tanks were cleaned and dead fish removed, weighed, and counted. Whenever possible, all fish were counted and weighed to the nearest 0.1 gm. During periods of heavy mortality it was often necessary to weigh 50 dead fish at random, calculate the mean net weight, and divide the figure into the total weight to estimate the number of dead. These estimates have an average maximum error of about 5 percent. When designated by the experimental plan, fish were fed three times daily (at about 0830, 1330, and 1630) on frozen brine shrimp. The amount of food varied between experiments depending on the size, number, and condition of the fish.

The total experimental period was usually 14 days (from 12 to 16 days), depending upon objectives.

Length-weight data

In some experiments, random samples of 25 live fish were removed to determine standard length and wet and dry weights. Excess water was removed from the dead nehu by quickly blotting with a paper towel. Standard length was measured to ± 0.1 mm and wet weight of fish was determined on a Semi-micro Mettler Balance (H16) to ± 0.5 mg. Samples were placed in a mechanical convection oven (Theco Model 18) and dried at 60°C for 24 hours. Dry weights were then determined by a similar procedure as described for wet weights.

RESULTS AND CONCLUSIONS

In the following section, variables of laboratory and barge experiments are examined separately using one or two successful experiments to illustrate conclusions. Some experiments were unsuccessful due primarily to equipment failures, i.e., power and pump failures, and poor water quality. Data from such experiments were not included in the "analyses" section.

Results of Field Work

Day capture

Three out of four attempts to capture nehu by bait seining were successful. At times it was necessary to make more than one set, but never more than three. The occasional lack of success in capturing nehu was attributed to the following reasons: (1) adverse weather conditions made nehu concentrations difficult to locate, (2) insufficient numbers of nehu were seen, or (3) the size of nehu was too small. Several "blind sets" made when nehu could not be visually located were always unsuccessful and subsequently discontinued.

Night capture

Of the 78 sets made at night from the barge, 45 sets (58 percent) were unsuccessful and 33 sets (42 percent) were successful, yielding 1 or more buckets of nehu. Since the possibility exists that nehu may have approached the light but left before the net was lifted, an estimate of at least 50 percent success in attracting nehu to night lights seems reasonable.

A factor analysis (Dixon, 1970) was applied to environmental data using an IBM 360 computer. The results are summarized in Tables 1 to 4. However, a limitation is imposed on the results since all negative catches do not necessarily indicate absence of nehu.

Eleven--one dependent and ten independent--variables were evaluated: (1) buckets of nehu captured (dependent variable), (2) month, (3) moon phase, (4) tidal sequence, (5) tidal range, (6) time from sunset of lowest low tide, (7) weather, (8) turbidity, (9) temperature, (10) salinity, and (11) presence of predators. The correlation and factor matrices for these variables can be found in Tables 1 and 2. Percentage of capture success and number of buckets captured were significantly less in spring than the rest of the year (Table 3). Significantly more nehu were captured during the first quarter moon phase (Table 4). The greater number of predators occurring during the last quarter may have reduced capture success during that phase. The influence of tidal factors appears negligible. The influence of weather upon capture success is not known since most attempts of night capture were made during good weather.

Several organisms other than nehu were also attracted to night lights during night baiting. The most common observed fishes were *Pranesus insularum* and *Etrumeus teres* which are also used as baitfish for skipjack tuna. Predators observed attacking or feeding on nehu under the light include *Caranx mate, C. melampygus, Gnathanodon speciosus, Scomberoides lysan, Trachurops crumenopthalmus,* and *Decapterus maruadsi*. A complete list of species observed under night lights, the months of occurrence, relative abundance, and observations of predation are given in Table 34.

Results of Laboratory and Barge Experiments

Types of mortality curves

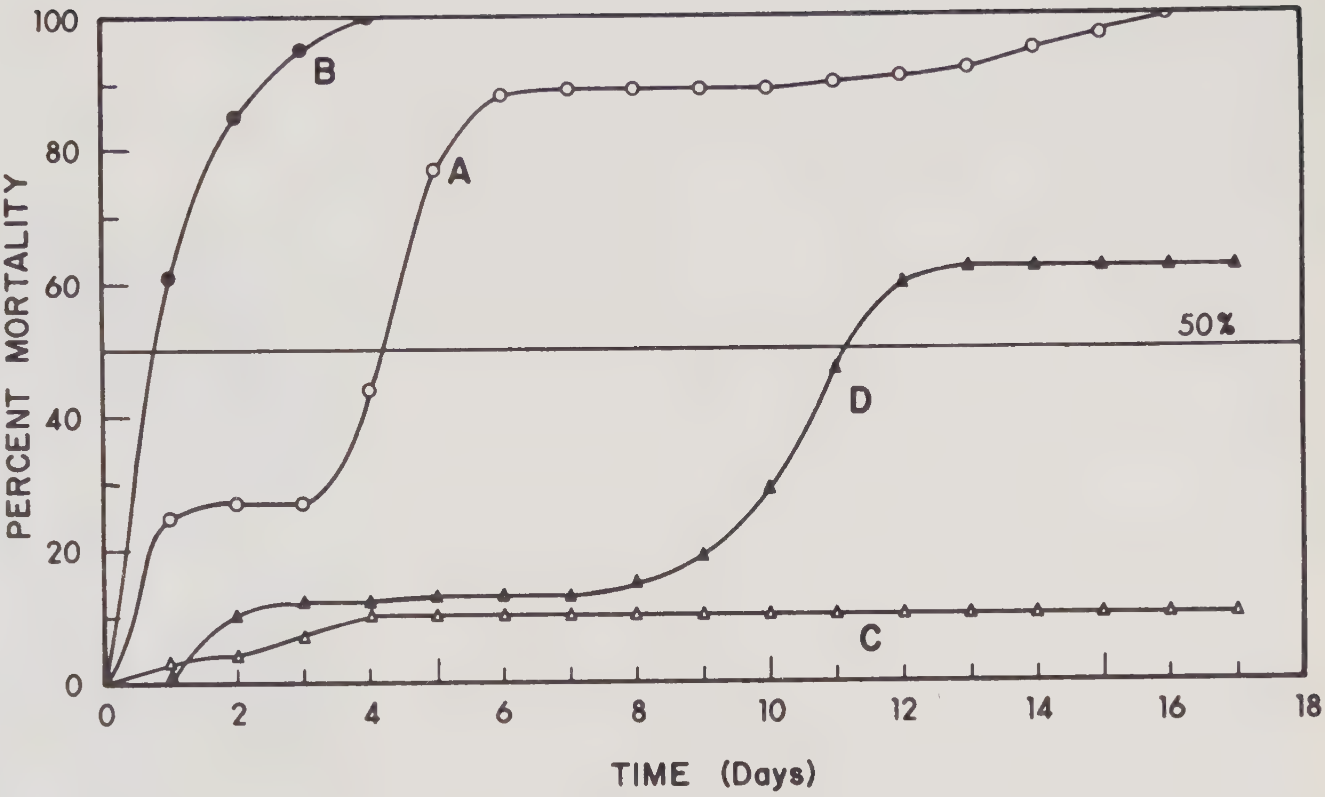
During initial experiments, certain patterns of mortality emerged. To provide a basis for comparison between results of the following experiments, types of mortality are described below. Mortality of nehu in captivity is clearly illustrated by cumulative percentage of mortality curves. The percentage of mortality (Y) is defined as the total number dead by day (X) divided by total number of fish at the beginning of the experiment (X = 0). The cumulative percentage of mortality is shown as a function of time in days (Y = f [X]). The shape of the curve is determined by the interaction of inherent and environmental factors producing stress and mortality in the nehu. The characteristics of the mortality curve used in comparing experiments are: (1) percentage initial mortality (percentage of dead [Y] by end of Day 1 [X = 1]); (2) day on which delayed mortality begins (X = m); (3) time interval over which delayed mortality occurs

$(X_n - X_m)$; (4) day on which delayed mortality ceases $(X = n)$; (5) extent or range of percentage of delayed mortality $(Y_n - Y_m)$; (6) day of 50 percent mortality $(Y = 50)$; and (7) percentage of surviving at asymptotic mortality level after delayed mortality has occurred (Y_∞, or maximum percentage of mortality). Further discussion of the mortality curves is in the "conclusions" section.

Figure 2 typifies commonly observed mortality curves in populations of captive nehu. The curves represent results of environmental conditions ranging from maximum stress (i.e., fishing vessels with unimproved wells) to minimum stress (i.e., optimal environment produced by experimental improvements).

In Figure 2 is a mortality curve (B) typical of a maximum stress environment. Handling of fish was by bucketing. The fish were further injured in bait wells under rough seas where insufficient oxygen was present, fish were disoriented, and 100 percent seawater produced osmoregulatory stress in injured fish. Initial mortality (primarily from injuries) under these conditions was high; more than 50 percent were dead by the end of Day 1 and all fish were dead by the end of Day 4. Mortality increased logarithmically until all fish were dead. There was no time interval over which there was no mortality.

In Figure 2, curve A shows the mortality pattern commonly encountered in early experiments with partial bait-well improvements. Fish were bucketed and sufficient oxygen was present, but 100 percent seawater induced osmoregulatory stress. In such a case, initial mortality is relatively high and for a short period thereafter, no mortality occurs. Subsequently, mortality increases rapidly until an asymptotic level where no further mortality is reached (Days 6 through 10). The early period of



A = partial improvement of tank or well environment
B = maximum stress environment
C = optimal environment
D = further improvement of environment than (A)

Figure 2. Examples of typical mortality curves of *S. purpureus* in captivity.

no mortality (Days 1 through 3) is defined here as the "stage of resistance" (Selye, 1950). The period of increasing mortality (Days 3 through 6) is defined as the "stage of exhaustion" or "delayed mortality" or "stress mortality." The characteristics of the curve vary depending upon environmental conditions and alleviation of stress. For example, addition of current or stronger light intensity may increase the time before onset of delayed mortality. Unless conditions are optimal, however, delayed mortality nearly always occurs. The mortality curve A in Figure 2 is sigmoid from Days 1 through 7 and shows that mortality may again increase exponentially following Day 10 until all fish are dead. This occurs from approximately Days 12 through 14 when fish are not fed and begin dying of starvation. It also occurs when fish gills are infected with protozoan cysts.

Curve D in Figure 2 is a mortality curve resulting from reducing osmoregulatory stress of injured fish by initially placing them in 50 percent seawater. In this example other factors were also optimal. Characterisitcs of this treatment are low initial mortality (less than 1 percent) and a long stage of resistance (Days 2 through 8) before delayed mortality begins (Day 8). The extent of delayed mortality (from Days 8 through 12) is also reduced, with more fish surviving. Occasionally during particularly optimal conditions, even though fish are roughly handled, placing them into 50 percent seawater completely eliminates delayed mortality.

Finally, curve C in Figure 2 shows the effect of careful handling (e.g., by swimming fish into wells) and placing of fish into 50 percent seawater. All other factors were optimal. Little or no mortality occurred throughout the experimental period and no delayed mortality occurred at all.

Fish that were carefully handled, although placed in 100 percent seawater, also suffered much less delayed mortality than usual.

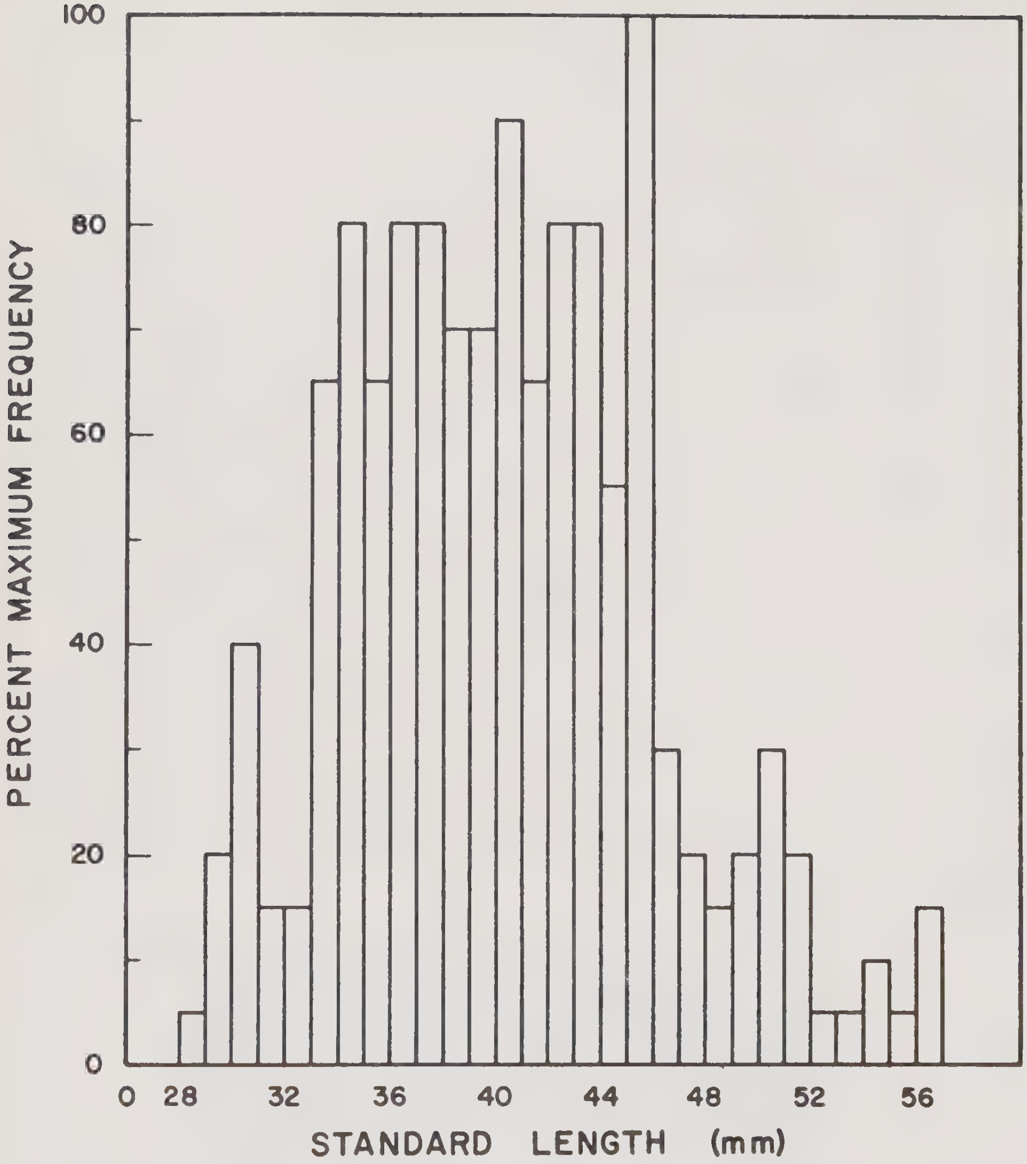
Factors affecting mortality

These factors are divided into inherent and environmental variables.

Inherent variables. Several characteristics inherent to nehu populations probably affect subsequent survival in captivity. It was not possible to assess, for example, genetic variation and previous environmental history completely. The effects of size, sex ratios, disease, and acclimation are partly assessed below.

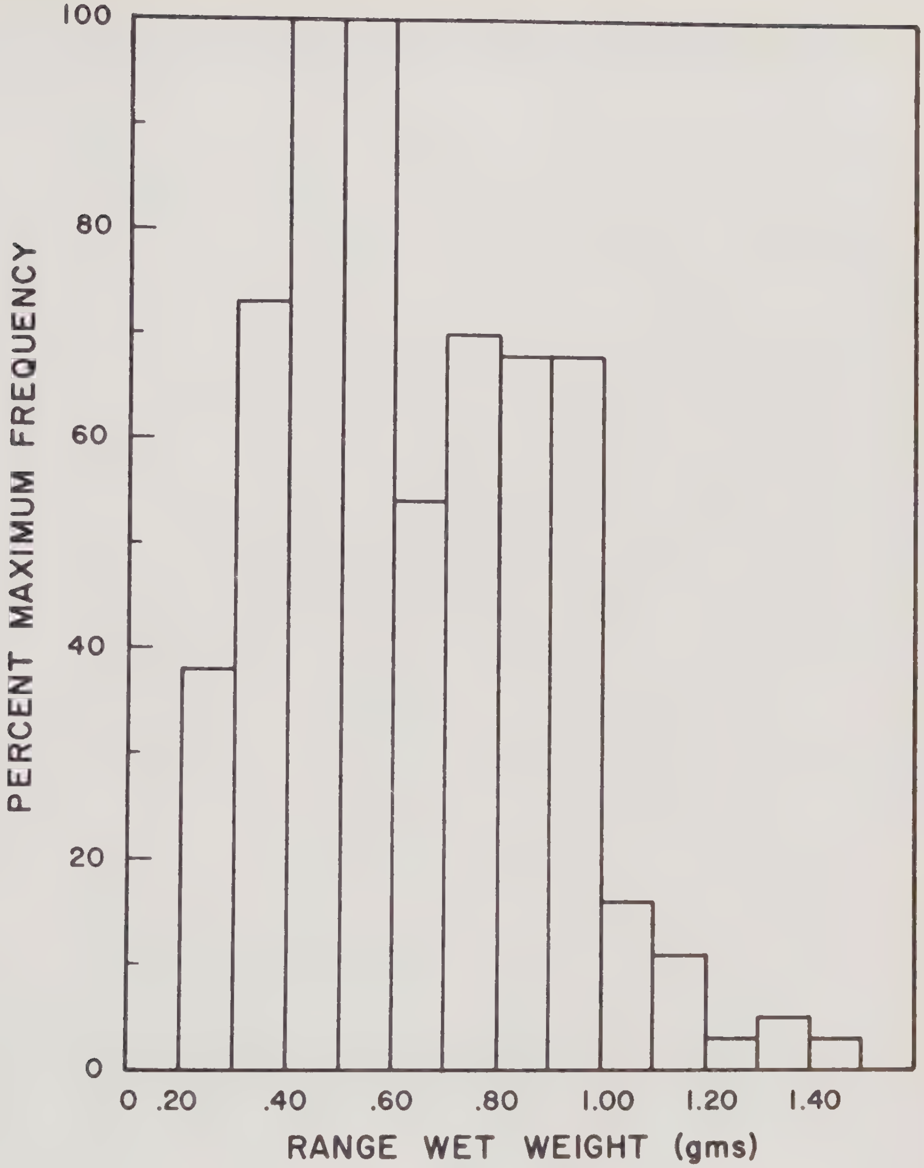
1. Size. Figures 3, 4, and 5 show the frequency distributions of standard length and wet and dry weights of fish randomly sampled just after capture (10 barge and laboratory experiments; 10 samples of 25 fish each). The range in standard length is approximately 28.0 to 60.0 mm. Most fish in the samples are post-metamorphic juveniles and adults (Plate 17). According to Yamashita (1951) metamorphosis occurs at approximately 30 mm. The frequency distributions approximate a normal distribution with no apparent year classes.

Plate 17. Post-metamorphic juveniles and adult nehu used in most of the experiments. The standard length ranged from 28.0 to 60.0 mm.



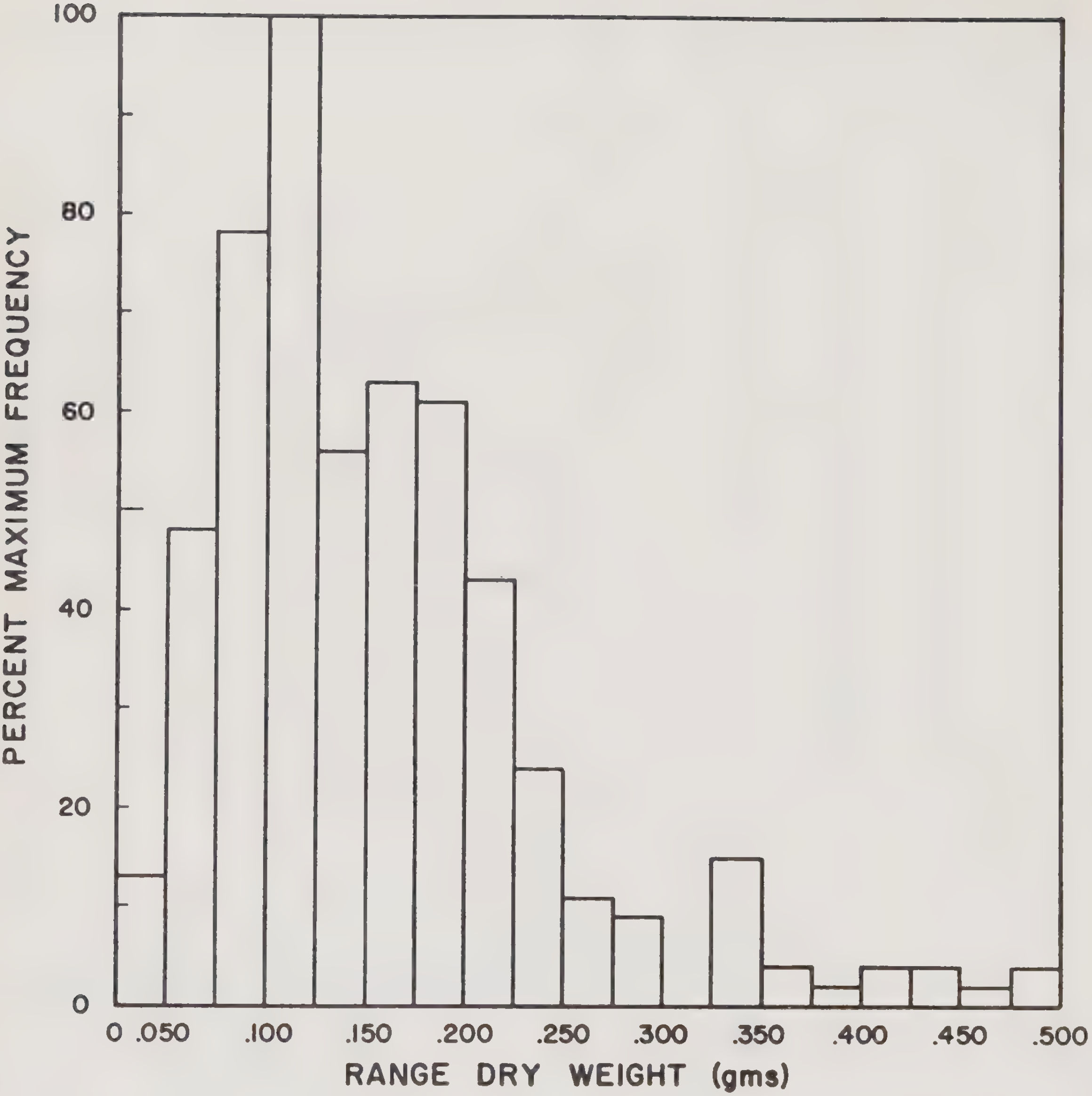
Total n = 225
Mean SL = 40.2 mm

Figure 3. Frequency distribution of standard length of post-metamorphic *S. purpureus* based on ten random samples of 25 fish per sample.



Total n = 225
Mean WW = 0.634 gm

Figure 4. Frequency distribution of wet weight of post-metamorphic *S. purpureus* based on ten random samples of 25 fish per sample.



Total n = 250
Mean DW = 0.156 gm

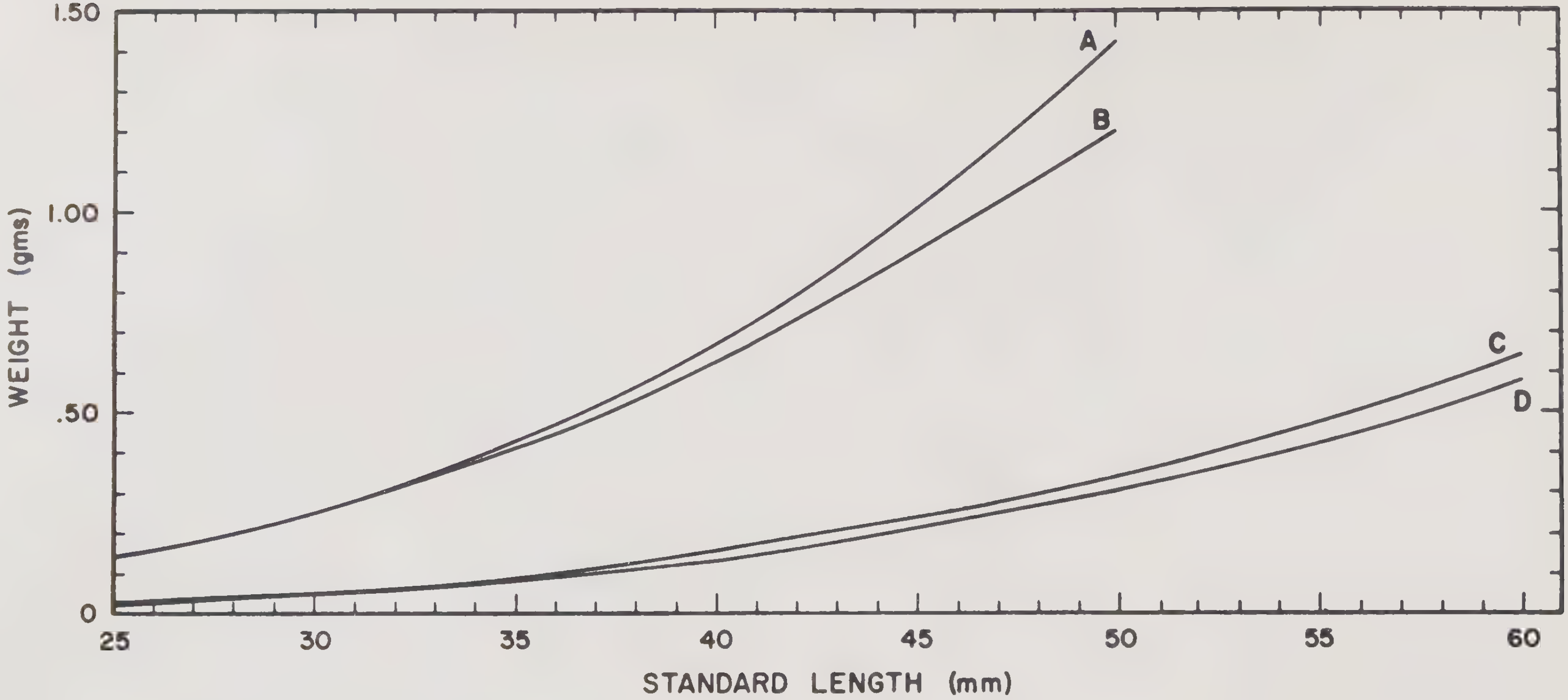
Figure 5. Frequency distribution of dry weight of post-metamorphic *S. purpureus* based on ten random samples of 25 fish per sample.

Size data are summarized in Table 5. Mean standard length, wet weight, and dry weight are 40.2 mm, 0.634 gm, and 0.156 gm, respectively for the total sample. The mean dry weight-wet weight ratio is 0.246 (25 percent dry weight) and the mean percentage of body water is 75 percent. The size of fish in laboratory samples is less than in barge samples. This probably reflects the fact that whereas most laboratory samples were day bait, most barge samples were night bait and larger fish are frequently caught at night.

The calculated regressions of wet and dry weights on standard length are shown in Figure 6. Regressions of wet weight on standard length are described by a power function ($\hat{Y} = aX^b$) where $\underline{b}$ = 3.366 in the laboratory sample (Figure 6, curve B) and $\underline{b}$ = 3.109 in the barge sample (Figure 6, curve A). The difference in $\underline{b}$ is probably due to the different size ranges of the two samples. Regression of dry weight on standard length is also a power function with $\underline{b}$ = 3.584 in the laboratory sample (Figure 6, curve D) and $\underline{b}$ = 3.606 in the barge sample (Figure 6, curve C). The two regressions are similar in this case.

Survival varied with size (also found by Brock and Takata, 1955). Smaller fish died earlier, with more larger fish surviving at the end of the experimental period. This was observed in all experiments. An example is given in Table 6 which compares the mean wet weight of dead fish on Day 1 and the mean wet weight of live fish on Days 1 and 14 for four experiments. Younger fish are probably injured more easily and are more susceptible to stress conditions in captivity.

2. Sex ratios. There is apparently considerable variation in sex ratios as determined from inshore samples of nehu (T.A. Clarke, 1971: personal communication). Of four samples (40 fish per sample) from four different



A = wet weight (gm) vs standard length (mm), barge samples ($\underline{a} = 6.53 \times 10^{-6}$,
$\underline{b} = 3.109$)
B = wet weight (gm) vs standard length (mm), laboratory samples ($\underline{a} = 2.72 \times 10^{-6}$,
$\underline{b} = 3.366$)
C = dry weight (gm) vs standard length (mm), barge samples ($\underline{a} = 2.25 \times 10^{-7}$,
$\underline{b} = 3.606$)
D = dry weight (gm) vs standard length (mm), laboratory samples ($\underline{a} = 2.69 \times 10^{-7}$,
$\underline{b} = 3.584$)

Figure 6. Calculated regression curves of wet and dry weights on standard length of *S. purpureus*.

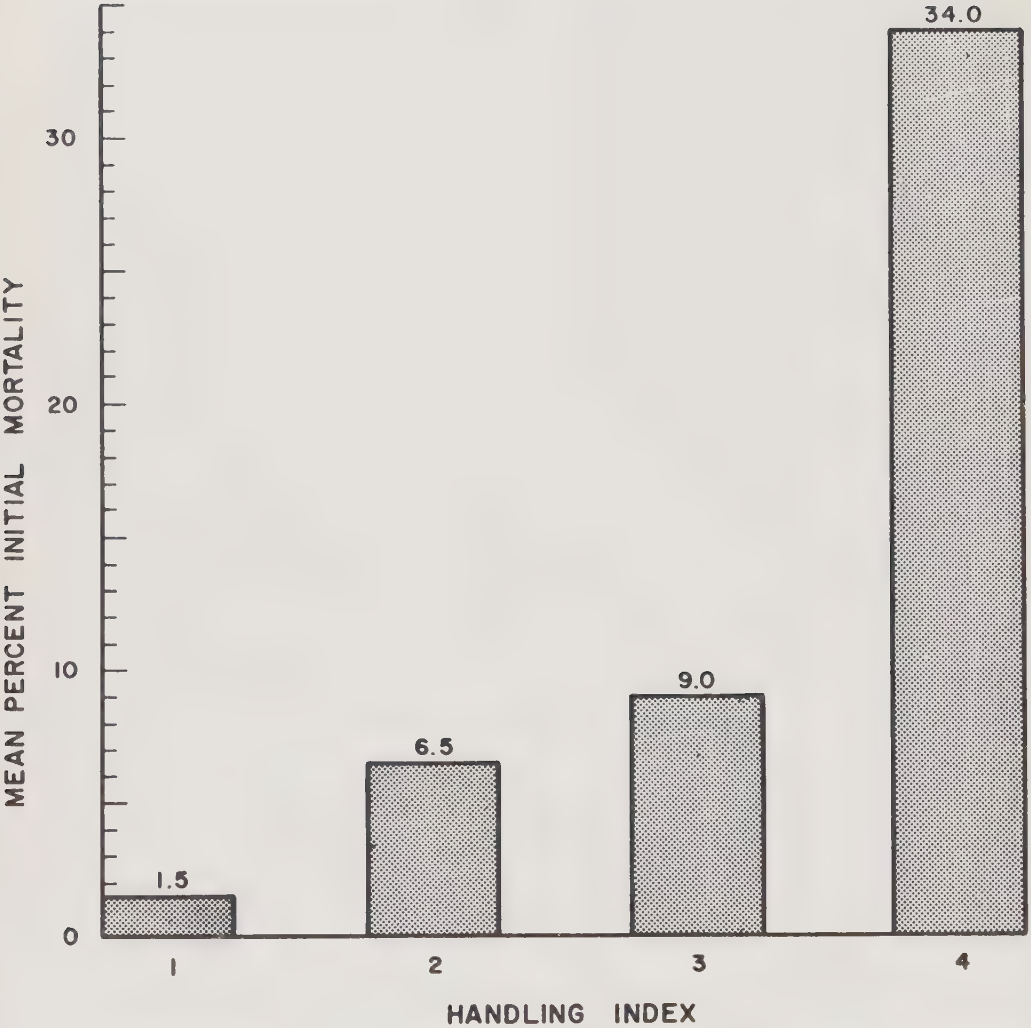
experiments, three were found with a 1:1 sex ratio and the fourth with slightly more males. When the four samples were combined, the sex ratio was approximately 1:1, with 52 percent males and 48 percent females. Differential mortality between sexes was not measured.

3. Disease. The effect of protozoan parasites on mortality in captivity is often considerable. Although gills of fish from the natural populations were infected with protozoan cysts, the summer examinations of fish when first captured indicated that the infection was usually light (one to five cysts per gill chamber). It is possible, however, that cysts may contribute to stress in fish during the first few days after capture. Infections increased over the experimental period and it is possible that definite stress and mortality may eventually occur.

4. Acclimation. In a few experiments, nehu were maintained in barge bait wells for 14 to 20 days before they were transferred to the laboratory. The period of acclimation eliminates delayed mortality from handling. Only a small initial mortality from handling occurred after transfer to the laboratory. The mean percentage of initial mortality in acclimated fish after transfer was only 1.5 percent (range = 0 to 5 percent) as opposed to 9.0 percent (range = 1 to 18 percent) initial mortality in unacclimated fish handled and transferred in the same way.

Environmental variables. Environmental variables affecting survival of nehu in captivity are discussed in the order of importance. Interactions are briefly considered; a detailed discussion of interactions is given with the factor analysis in the "conclusions" section.

1. Handling. The effect of increased handling on initial mortality of nehu is shown in Figure 7, which gives mean percentage of dead by the end of



Handling Index:
1 = night bait, transferred by swimming directly into barge wells
2 = day bait, transport time 50 to 70 min, transferred by swimming into barge wells
3 = night bait, transport time 10 to 20 min, bucketed into laboratory tanks
4 = day bait, transport time 50 to 70 min, bucketed into laboratory tanks

Figure 7. Effect of handling on initial mortality of *S. purpureus* placed in 100 percent seawater during capture.

Day 1 for all experiments with 100 percent seawater. Most fish died directly from lacerations and contusions suffered during capture and transfer. In barge experiments where fish were captured by night baiting and then transferred by swimming directly into the bait wells with little or no handling (Handling Index [HI] = 1; Figure 7), the mean initial mortality was only 1.5 percent (range = 0 to 3 percent). When fish were captured by day baiting, transferred by swimming into the bait receiver, transported for 50 to 70 minutes, and finally transferred by swimming from the bait receiver into the barge bait wells (HI = 2), the mean initial mortality was 6.5 percent (range = 1 to 16 percent). In laboratory experiments, fish were sometimes captured by night baiting, transferred by swimming from the barge net into the bait receiver, transported for 10 to 20 minutes to the laboratory, and finally bucketed from the bait receiver into the laboratory tanks (HI = 3). In this situation, mean initial mortality was 9.0 percent (range = 1 to 18 percent). If fish were captured by day baiting, transferred by swimming into the bait receiver, transported to the laboratory in 50 to 70 minutes, and finally bucketed from the bait receiver into laboratory tanks (HI = 4), the mean initial mortality would be relatively high (34.0 percent; range = 5 to 63 percent). Clearly, increased handling is deleterious to survival. Furthermore, stress induced by handling is responsible for most succeeding delayed mortality.

2. Salinity. The effect of salinity on survival is related to handling of nehu. The integument of the fish is injured and scales and mucus are lost. The results of this study and those of Maginniss (1970) show that roughly handled nehu placed into 100 percent seawater (34.0 to 36.0 ppt) immediately after capture undergo osmoregulatory stress, loss

of body water and a simultaneous increase in blood serum chloride and osmotic pressure.

With lacerations and loss of mucus and scales, fish lose water by increased exosmosis and possibly also by shock diuresis. Normally, nehu contain approximately 79 to 82 percent body water ($\frac{\text{wet weight - dry weight}}{\text{wet weight}}$ X 100). When they are placed in laboratory tanks containing 100 percent seawater, body water decreases a mean of 3 percent to a minimum range of about 74 to 77 percent. Most body water is lost within 1 to 3 hours after capture; the recovery period varies with the extent of injuries and conditions of the capture environment. In 100 percent seawater, partial recovery usually occurs by the end of Day 1 and complete recovery by Days 10 through 14.

The normal range of serum chloride is approximately 150 to 160 mEq/liter (Maginniss, 1970); the maximum recorded is approximately 180 mEq/liter. The mean percentage of increase in serum chloride is approximately 8 to 10 percent, occurring 1 to 3 hours after capture, the same period as maximum water loss. The recovery pattern of serum chloride is similar to that of body water--partial recovery by the end of Day 1 and complete recovery by Days 10 through 14. At least part of the serum chloride increase may result from fish swallowing seawater to compensate for water loss (Maginniss, 1970). During recovery, fish must excrete chloride through gills by means of active transport.

The normal range of serum osmotic pressure is approximately 340 to 405 mOsm/liter (Maginniss, 1970). The serum osmotic pressure also increases in the first 1 to 3 hours of capture. There are insufficient data to state the mean percentage of increase with certainty; limited data indicate it is about 10 percent. The recovery pattern is similar to that of body water and serum chloride.

Nehu are hypoosmotic in seawater and must continually compensate osmotically by swallowing more water and eliminating excess salts. This process requires energy. When mucus and scales are lost, osmoregulatory stress is increased greatly, requiring further energy for regulation. That many individuals cannot compensate is indicated by the high rate of delayed stress mortality after the resistance stage. A more comprehensive discussion of osmoregulation of nehu is given by Maginniss (1970).

Data from Maginniss (1970) and results of this study indicate that the most favorable salinity range for decreasing osmoregulatory stress and increasing survival is from 40 to 60 percent seawater (approximately 14.0 to 22.0 ppt). The blood serum osmotic pressure averages about 400 mOsm/liter or approximately 40 percent osmotic pressure of seawater. To minimize osmotic stress while permitting a margin of error if salinity control fails and salinity drops, 50 percent seawater (approximately 17.5 ppt) appears optimal for increasing survival experimentally.

Tests by Brock and Takata (1955) showed that mortality of nehu was greater in 100 percent rather than 50 percent seawater. They concluded that brackish water treatment of a few hours might increase survival. This work was continued in the present study.

In most of the salinity experiments, 50 percent seawater (16.0 to 20.0 ppt; mean of 17.5 ppt) was used to test the effect of reduced salinity on mortality of nehu. Several experiments were conducted varying the length of exposure to reduced salinity. When the percentage of initial mortality of nehu in all experiments with 50 percent seawater (irrespective of exposure time) was compared with the percentage of initial mortality in 100 percent seawater, a highly significant difference ($P < 0.001$) was found (Table 7). The mean percentage of initial mortality in 100 percent seawater (23.4 percent) was approximately five times that in 50 percent seawater (4.7 percent).

Results of experiments with reduced salinity are summarized in Table 8 and the mortality curves shown in Figures 8 and 9. Both 50 percent and 100 percent seawater are circulated in an open system with supplemental oxygen and current. Additional experiments in a recirculated, closed brackish water system are discussed later.

In laboratory experiment 25B (Table 8; Figure 8), nehu were exposed to varying periods of low salinity. Examination of Figure 8 shows that greatest initial mortality, earliest delayed mortality and 50 percent mortality, and greatest total mortality by Day 12 occurred in 100 percent seawater (Figure 8, curve B). Even brief exposure to 50 percent seawater enhanced survival by decreasing initial mortality and prolonging onset of delayed mortality (Figure 8, curve A). An exposure of 6 hours (Figure 8, curve C) was nearly equivalent to that of 24 hours (Figure 8, curve D) in increasing survival. Since the first 1 to 3 hours after capture is the period of greatest osmoregulatory stress, the results are understandable. It is therefore most important to reduce salinity to facilitate recovery in those first few hours after capture. Although exposure to reduced salinity decreased initial mortality and prolonged the onset of delayed mortality, delayed mortality still occurred, indicating that alleviation of stress was still incomplete.

In barge experiment 18 (Figure 9), mortality was greatly decreased by exposing fish to 50 percent seawater for only 4 hours (Figure 9, curve A). Some delayed mortality occurred, but 50 percent mortality was never reached

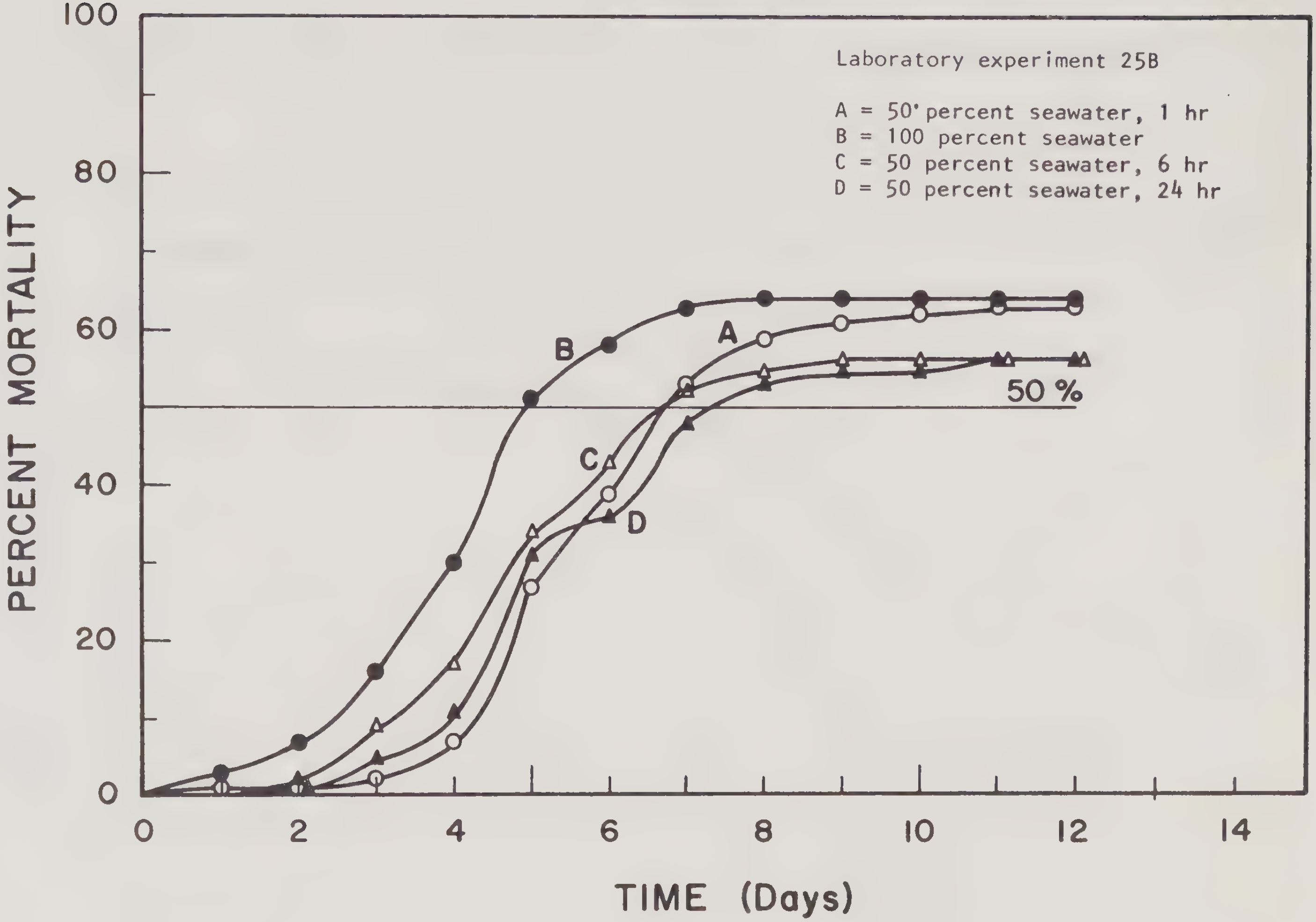


Figure 8. Effect of various exposure times to reduced salinity on mortality of *S. purpureus* in open system.

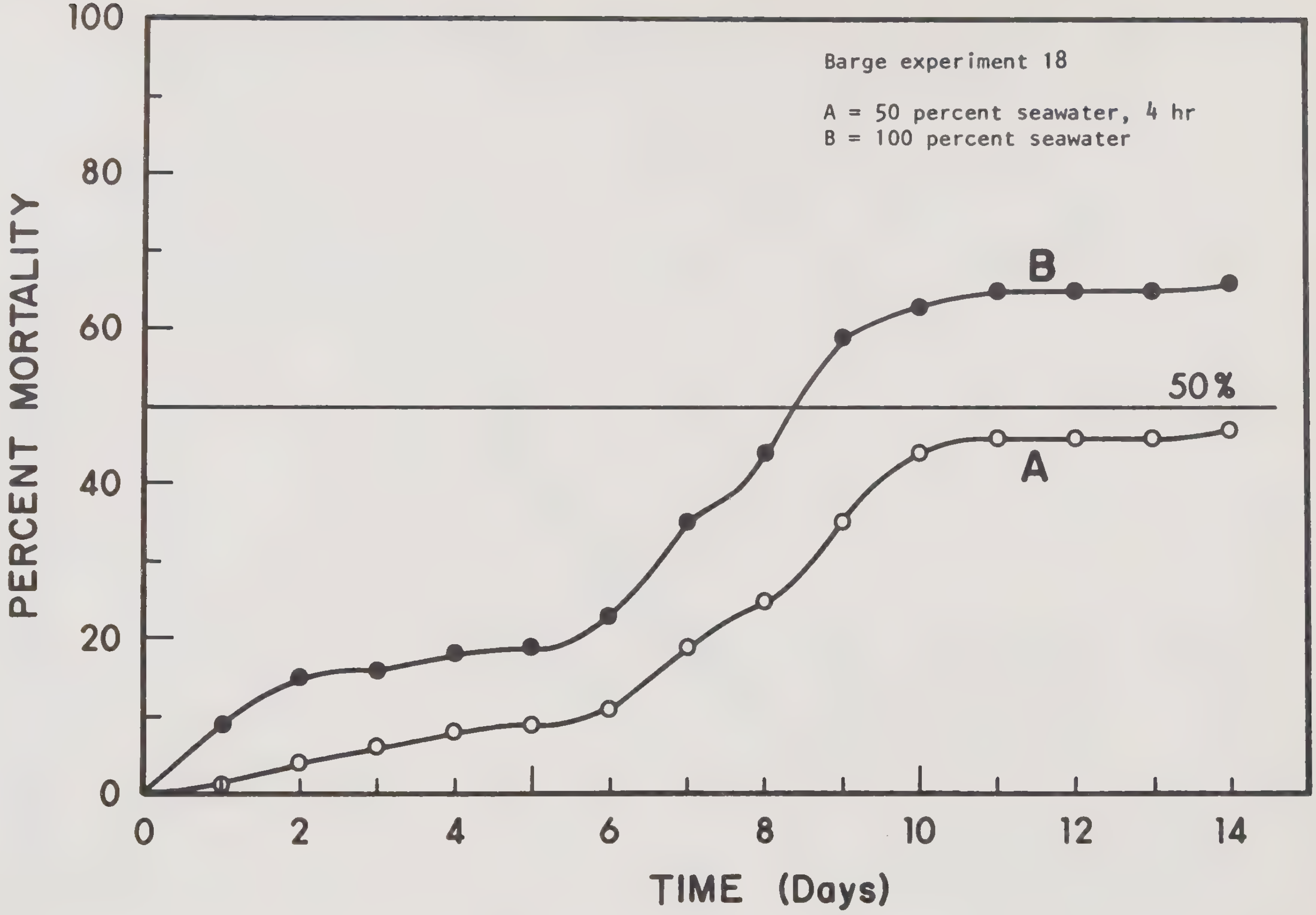


Figure 9. Effect of reduced salinity on mortality of *S. purpureus* in open system.

and 53 percent remained on Day 14. In 100 percent seawater (Figure 9, curve B) 50 percent mortality occurred by Days 8 to 9 and only 34 percent remained on Day 14.

Interaction of salinity with oxygen is reflected in the recovery of body water under different oxygen regimes. Table 9 summarizes results of two experiments (laboratory experiments 12 and 13) where oxygen treatment was varied (supplemental air vs supplemental oxygen). These experiments were conducted in 100 percent seawater where maximum body water loss occurred. There is a significant difference between the two treatments in percentage of body water regained by Day 14 ($P < 0.01$). In tanks with air, mean oxygen ranged from 5.0 to 6.0 ppm; in tanks with oxygen, from 6.5 to 8.0 ppm. Mean percentage of increase in body water in tanks with air was 0.44 percent and full recovery was incomplete by Day 14. In tanks with oxygen, mean percentage of increase in body water was 2.36 percent with nearly complete recovery by Day 14. It appears that high oxygen concentrations facilitate osmoregulation and thereby reduce stress. Several other experiments in which supplemental oxygen was not provided and critically low oxygen levels occurred also show that recovery of body water is incomplete by Day 14. In 100 percent seawater, complete recovery of body water takes place only when oxygen is maintained at saturation.

3. Oxygen. Sufficient oxygen is necessary to sustain the metabolic activity of nehu and is especially important in affecting survival in captivity when stress is increased. Critically low oxygen concentrations frequently occur in unimproved bait wells. No Hawaiian live-bait vessels provide supplemental air or oxygen: oxygen is replaced with seawater entering bung-holes on the bottom of the bait wells. A few vessels have pumping systems which circulate water rapidly through wells. In this case,

the oxygen concentration increases with increased flow rate. Figure 10 shows the oxygen concentration (ppm) in bait wells on the *Buccaneer*. Data show that oxygen falls to critical low levels in wells with no pumping system, especially when the vessel is stationary in Kewalo Basin. When the vessel is under way, oxygen concentration usually rises. Observations on the *Buccaneer* and other vessels lead to the conclusion that oxygen depletion is a major factor contributing to high bait-well mortality, particularly if there are no circulation pumps.

Oxygen consumption of nehu under various environmental conditions is summarized in Table 10. Active oxygen consumption in groups of nehu was measured and the values of oxygen consumption (cc oxygen/gm fish/hr) were determined from the linear regression coefficient $\underline{b}$. Often, however, the regression is not linear but curvilinear. Figure 11 demonstrates that oxygen consumption is usually higher in the first 1 to 2 hours, decreasing gradually to a constant linear decrease until an equilibrium level of oxygen concentration is reached (Figure 11, curves B and D). The consumption rates, therefore, are estimates only, assuming a constant rate of consumption. Time in these regressions spanned the period from the beginning of the experiment until an equilibrium level was reached, varying with density of fish and conditions of the capture environment. The level of equilibrium oxygen concentration is considered here as equivalent to the incipient lethal level (Prosser and Brown, 1961) or critical level (Pritchard, 1955).

Table 10 (section A) shows consumption rates of individual nehu as determined by Pritchard (1955). Pritchard did not measure wet weight of fish in his experiments, giving instead the standard lengths of six fish for experiments in August 1955. Using Pritchard's standard lengths and the regression of wet weight on standard length (Figure 6) of this study, the wet weight of

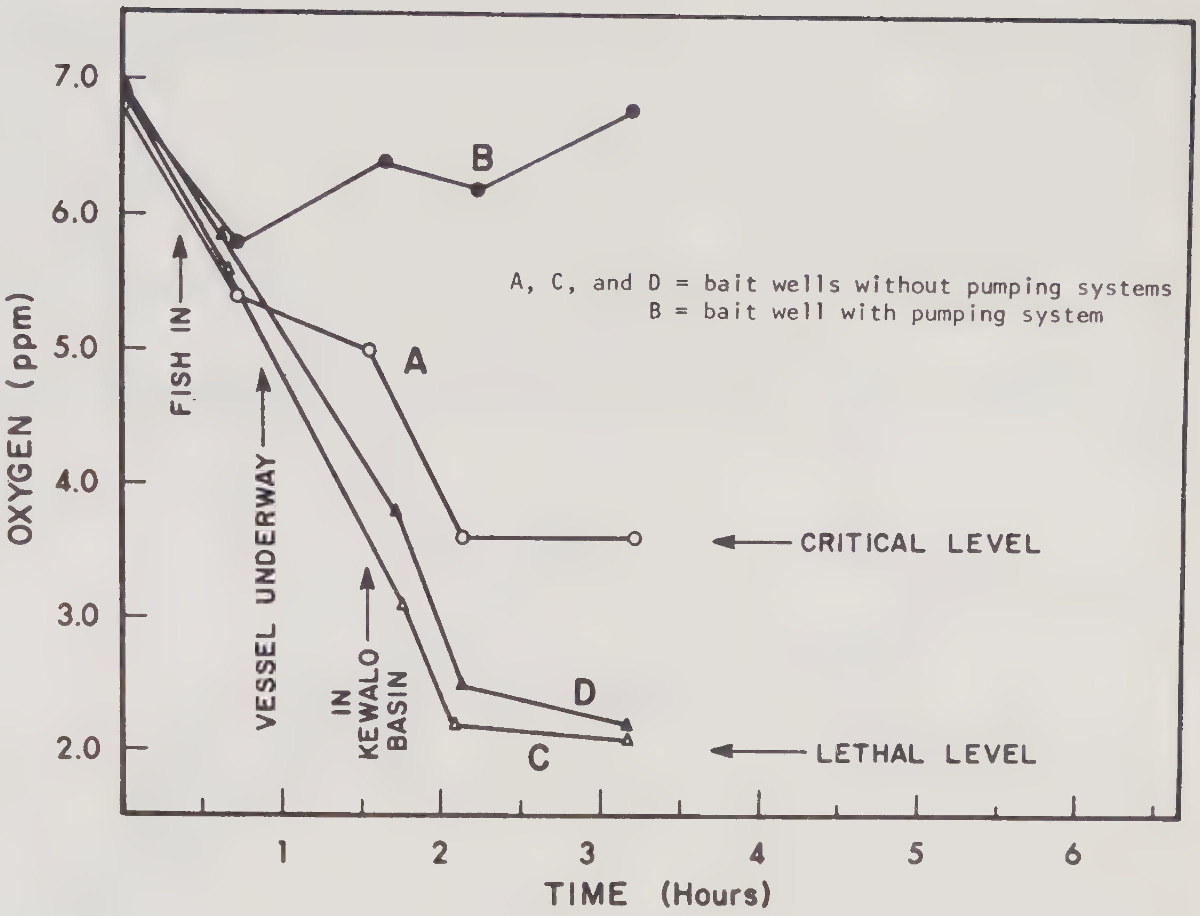
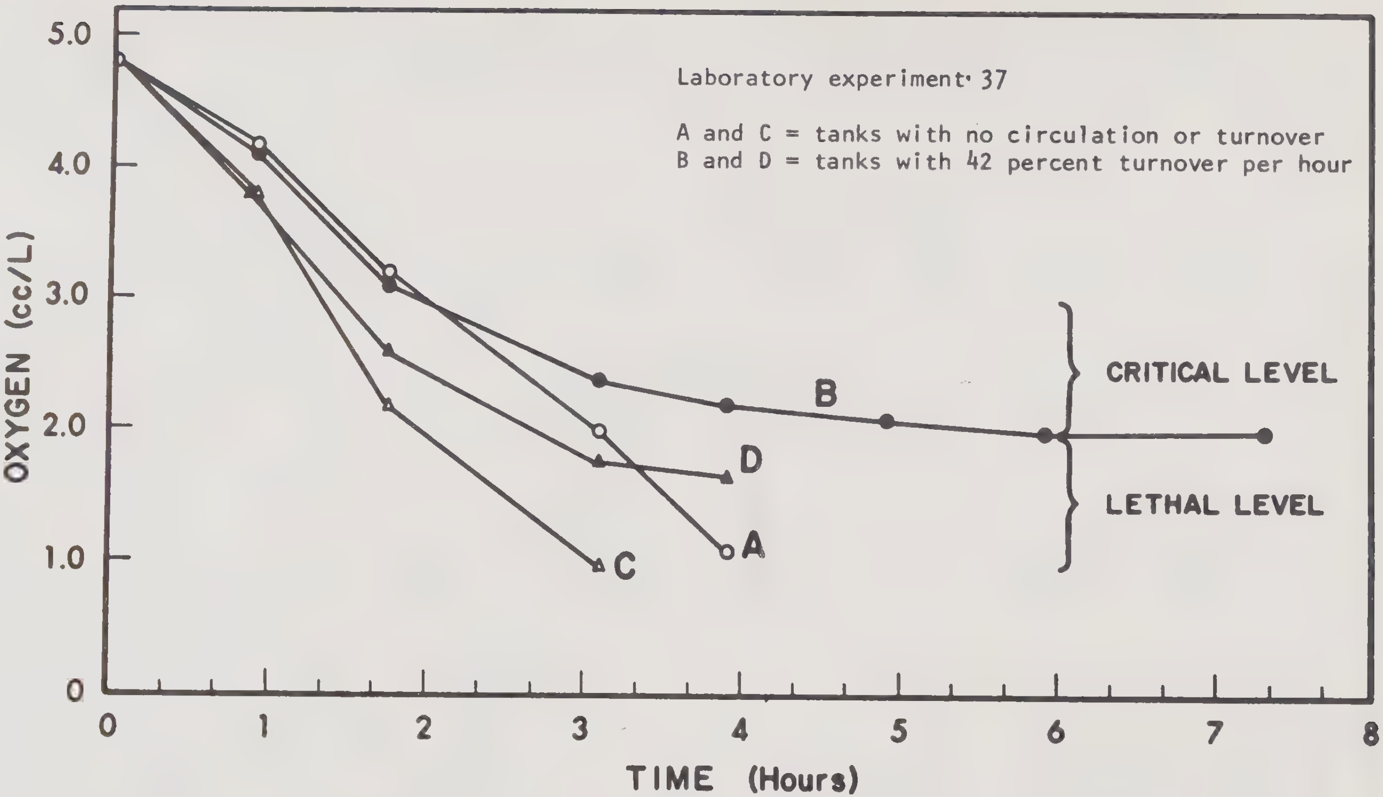


Figure 10. Decrease in oxygen concentration (ppm) in bait wells of the *Buccaneer* from time of *S. purpureus* capture until lethal level is reached in Kewalo Basin.



Linear decrease in oxygen (cc/gm/hr):

A - $\underline{b}$ = .601
B - $\underline{b}$ = .572
C - $\underline{b}$ = .883
D - $\underline{b}$ = .617

Figure 11. Decrease in oxygen concentration in laboratory tanks from the time *S. purpureus* is placed in tanks until lethal level is reached.

each length was estimated, and the mean consumption rate for six individual fish calculated to be 0.774 cc oxygen/gm fish/hr. The mean consumption of individual nehu appears to be approximately twice that determined by this study for acclimated groups of fish. The validity of this comparison is questionable, however, since Pritchard gave no description of acclimation.

Table 10 (sections B and C) shows rates of oxygen consumption determined for acclimated groups of fish. Nehu were acclimated for at least two weeks at approximately 25° to 28°C and were fed frozen brine shrimp (3 percent body weight/day) from Days 3 through 15 after capture. After two weeks, mortality ceased. Remaining fish were relatively larger and appeared healthy. In laboratory experiment 1 (Table 10, section B), two tests were conducted on the same group of fish on two successive days. The mean rate was 0.353 cc oxygen/gm fish/hr. In laboratory experiment 2 (Table 10, section C), oxygen consumptions of acclimated fish given different food treatments were compared. These fish were first acclimated then given different foods for 10 days, after which their oxygen consumption was measured. Those fed frozen brine shrimp exhibited the highest consumption rate; those without food, the lowest. Fish given other diets exhibited intermediate rates of consumption. These results substantiate other experiments showing that frozen brine shrimp is the best food for maintaining weight in captivity.

Oxygen consumption of unacclimated fish (measured on Day 1 after capture is higher than that of acclimated fish. Laboratory experiment 37 (Table 10, section D) shows that in tanks with no supplemental air, oxygen, circulation or current, mean oxygen consumption of nehu was 0.742 cc oxygen/gm fish/hr, approximately twice the rate of acclimated fish (0.354 cc oxygen/gm fish/hr.

With only circulation of water (Table 10, section E) mean rate of oxygen loss was 0.591 cc oxygen/gm fish/hr. Obviously, at this flow rate (4.8 liter/min; 1.3 gal/min) the turnover rate of water (42 percent per hr) is insufficient to replace oxygen consumed by the fish.

When air as well as circulation were provided (Table 10, section F), the mean rate of oxygen loss was 0.311 cc oxygen/gm fish/hr. Air and circulation were still insufficient to replace the oxygen lost through respiration.

A horizontal current, in addition to air and circulation (Table 10, section G), did not significantly change the rate of oxygen loss. The mean rate of oxygen loss was 0.292 cc oxygen/gm fish/hr.

Only when tanks were given supplemental oxygen (Table 10, section H) was saturation maintained regardless of oxygen consumption. Other experiments also clearly demonstrate that for average densities of unacclimated fish, supplemental oxygen or substantially increased flow rate is required to maintain saturation. Supplemental air does not usually provide enough oxygen to sustain saturation.

In some experiments oxygen concentration decreased rapidly to a lethal level (Figure 11, curves A and C) at a point when the first fish asphyxiates, loses equilibrium, sinks, and dies. In groups of fish, some individuals reach this level before others. The lethal value given here, therefore, represents the level of oxygen concentration at which the first death occurs. Time to this level depends on density of fish and initial oxygen concentration. Other environmental variables interacting with low oxygen may also raise the oxygen concentration level at which death occurs. For most experiments, the lethal oxygen level was approximately 1.0 to 2.0 cc oxygen/liter (1.3 to 2.7 ppm); the mean value, 1.4 cc oxygen/liter (1.9 ppm). At the equilibrium concentration or critical oxygen level (incipient limiting level of Prosser and Brown, 1961), the oxygen consumption of nehu becomes dependent on the oxygen concentration, which was from 2.0 to 3.0 cc oxygen/liter (2.7 to 4.0 ppm), mean value 2.5 cc oxygen/liter or 3.3 ppm. At the critical level fish decrease their consumption rate. Presumably, the longer the nehu must regulate their consumption, the more they are stressed. After some time (varying between experiments) at the critical level they are unable to decrease consumption further. Then oxygen concentration drops to the lethal level and death occurs. In a few instances, oxygen drops rapidly to the lethal level without any equilibrium period. This takes place when the density of fish is so great that there is insufficient oxygen to sustain fish long enough to regulate and decrease consumption. At lower densities, there is usually a regulation period at the critical level of oxygen concentration before a final decrease to the lethal level.

The mean lethal level of oxygen concentration determined here (1.44 cc oxygen/liter) is less than that determined by Pritchard (1955) of 2.02 cc oxygen/liter. The difference may be due to the fact that the value determined for this report was for groups of fish and his for individual fish.

Results indicate that oxygen concentration should not fall below 3.5 cc oxygen/liter (approximately 5.0 ppm). This concentration is well above the critical level (2.5 cc oxygen/liter; 3.3 ppm). However, since any oxygen concentration below saturation (approximately 4.0 to 5.0 cc oxygen/liter; 6.0 to 7.0 ppm at experimental temperatures and salinities) may create stress, the oxygen concentration should ideally be maintained at saturation by the addition of supplemental oxygen or increased flow rate.

Addition of industrial oxygen may result in high oxygen concentrations above saturation, particularly if oxygen flow is not carefully regulated. An upper limit of oxygen concentration was determined. The effects of high oxygen (over saturation to 20 ppm) varied, depending upon how fish were exposed. In laboratory experiment 32, fish were placed in high oxygen concentrations immediately after capture (Figure 12). The high oxygen concentration was deleterious. Greatest mortality occurred in tanks with highest mean oxygen concentration (Figure 12, curve C); lowest mortality in tanks with lowest mean oxygen concentration (Figure 12, curve B). In laboratory experiment 33, fish were placed in water at saturation immediately after capture and the oxygen concentration gradually increased to higher values. No significant difference in mortality due to different oxygen concentrations was observed in this case. It is unclear whether mortality in high concentrations is due to tissue damage from excess oxygen in blood vessels or to disorientation of fish by water disturbance. Microscopic examinations revealed no oxygen bubbles in blood vessels of the caudal fin.

These results suggest that fish should initially be placed in water at saturation or just slightly higher. If oxygen decreases during the first 3 hours, oxygen saturation can be maintained by gradually increasing the flow of oxygen until equilibrium is reached, usually by the end of the first day of captivity. For maximum survival oxygen concentration should never exceed 10 ppm.

Survival of nehu in different oxygen environments was contrasted in several laboratory and barge experiments. Of these, laboratory experiment 13 best shows the effect of supplemental oxygen in enhancing survival. Current was also provided in some tanks during this experiment. Figure 13 shows that mortality was highest in tanks provided only with air (Figure 13, curve B), lowest in tanks with supplemental oxygen and current (Figure 13, curve C), and

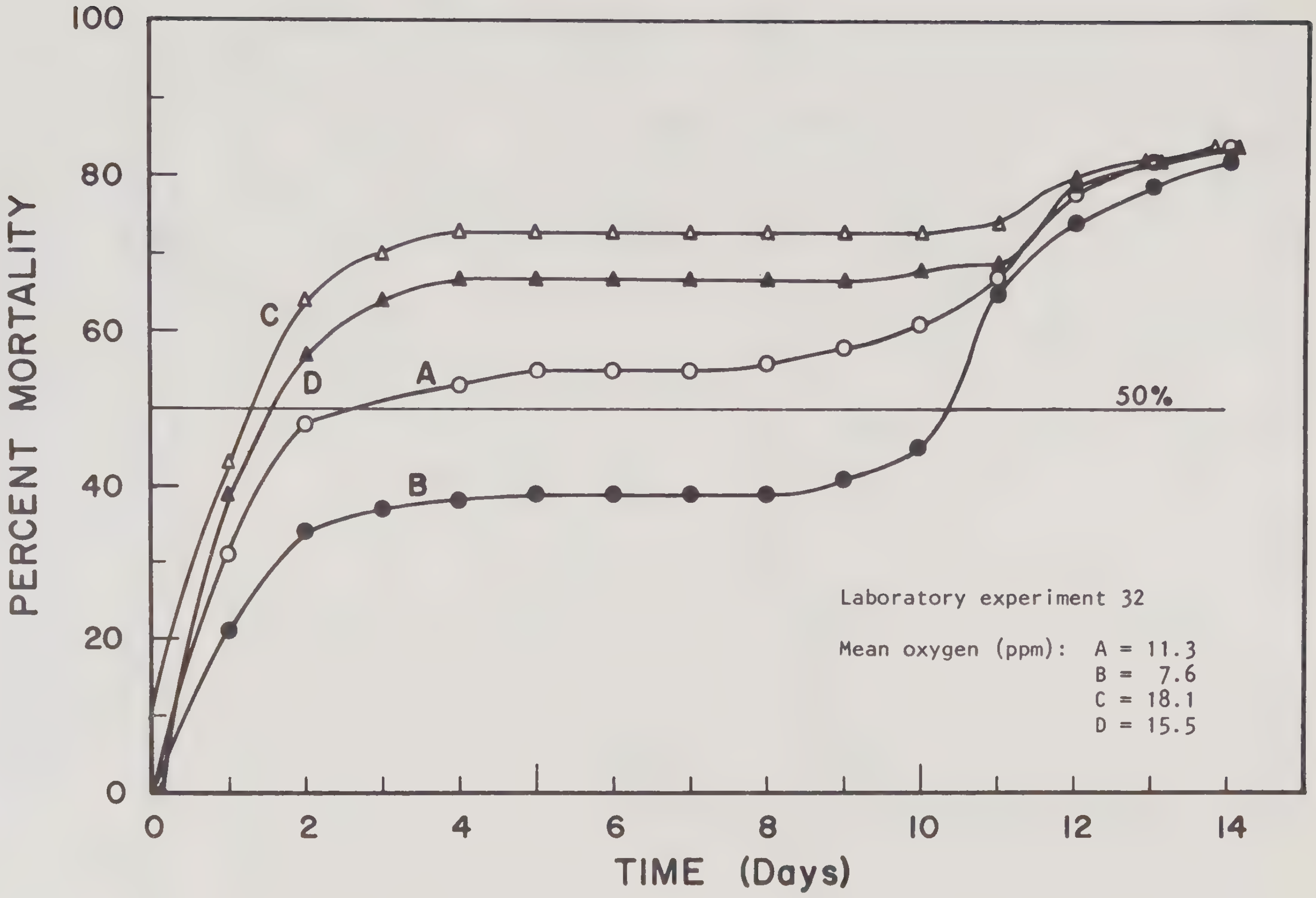


Figure 12. Effect of high oxygen concentrations on mortality of *S. purpureus*.

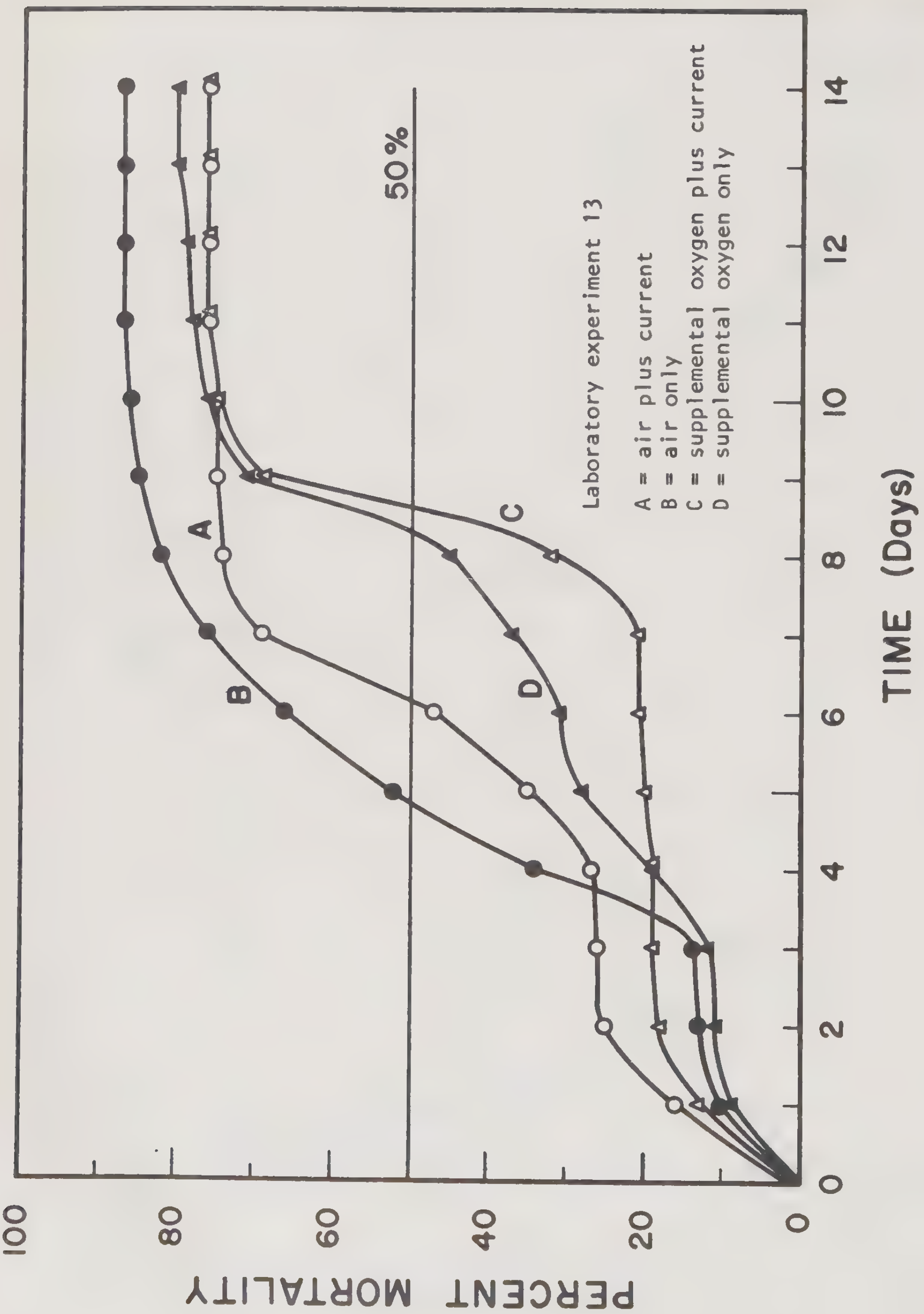


Figure 13. Effect of oxygen and current on mortality of *S. purpureus*.

intermediate in tanks with oxygen only (Figure 13, curve D) or with air and current (Figure 13, curve A). This is consistent with results of other oxygen experiments, although differences in mortality between air and oxygen treatments were often less pronounced than in laboratory experiment 13. Results depend largely upon the density of fish. In some experiments other mortality factors superceded the effect of oxygen, resulting in high mortality regardless of oxygen saturation. Usually, however, the provision of oxygen greatly increased survival. For example, in Figure 13, 50 percent mortality in tanks with oxygen did not occur until Day 8 or 9 as opposed to Day 5 or 6 in tanks with air. Although supplemental oxygen was used to maintain oxygen at saturation level, it did not eliminate delayed mortality, but often prolonged the onset of delayed mortality for several days.

In estimates of total oxygen consumed by a bucket of fish ($\bar{x}$ = 2,700 fish) at different consumption rates and mean wet weights (Table 11), consumption rates range from an estimated minimum (such as in acclimated groups of fish) to average consumption rates of single fish to an estimated maximum (Table 10). The mean wet weight of fish usually ranges from approximately 0.500 to 0.700 gm.

The supplemental oxygen apparatus is shown in Plates 11 and 12. A complete description can be found in Baldwin (1970), together with data showing the amount of oxygen (cc/min) released from the oxygen stone at pressures from 5 to 35 PSI. Table 35 gives line pressures providing sufficient oxygen for 1 to 10 buckets of fish.

The optimal oxygen environment for nehu requires:

a. Provision of supplementary oxygen as described.

b. Adjustment of oxygen line pressure to maintain oxygen at saturation concentration for experimental temperature and salinity.

c. Adjustment of oxygen stones and line pressure for the release of minimum-size bubbles to increase efficiency of oxygen dissolution in seawater.

d. Reduction of oxygen flow to minimum pressure necessary for saturation to reduce disorienting turmoil.

e. Oxygen concentration not to exceed a maximum of 10 ppm in 100 percent seawater.

f. Oxygen concentration not to decrease below 3.5 cc/liter (approximately 5.0 ppm).

4. Temperature. The range of temperature in Hawaiian waters is from approximately 20° to 30°C and lethal low or high temperatures normally are not encountered by nehu in captivity. During summer months, however, when at the upper end of this range (26.0° to 30.0°C), higher temperatures appear to interact with other factors to significantly increase stress and mortality.

Experiments on varying temperature were conducted in only laboratory experiment 19. Temperature control equipment ceased functioning after 7 days. Although temperature control was absent after this time, there is an indication that lower temperature prolonged the time to onset of delayed mortality. In Figure 14, the mortality curve (B) for fish treated with 100 percent seawater (34.0 to 36.0 ppt) and maintained at ambient temperature (26.0° to 28.0°C) shows that 50 percent mortality (3 to 4 days) occurred about 1 day earlier than with other treatments (50 percent mortality by Days 4 to 5). Fish subjected to 100 percent seawater but a lower temperature of 21.0° to 23.0°C reached the 50 percent mortality level by Day 5 (Figure 5, curve A). Those in 50 percent seawater (16.0 to 18.0 ppt) at 21.0° to 23.0°C reached the 50 percent mortality level by Days 4 to 5 (Figure 14, curve C), but initial mortality was significantly lower in 50 percent seawater than in either 100 percent seawater treatments.

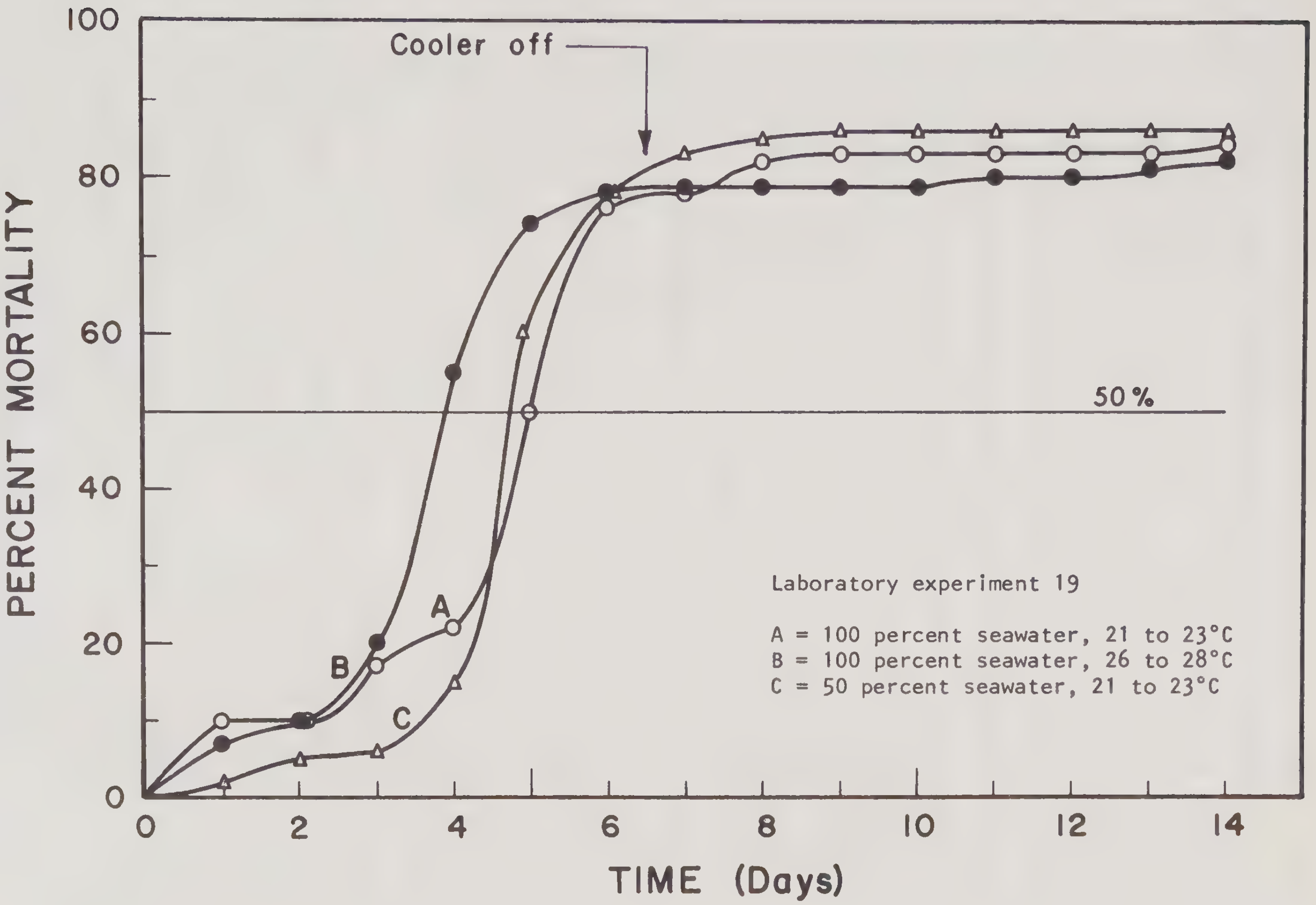


Figure 14. Effect of temperature and salinity on mortality of *S. purpureus*.

An analysis of mortality occurring at various temperatures, when measurements of temperature during all experiments are compiled, shows that temperature affects mortality. Analysis reveals that temperature does not significantly affect initial mortality or percentage of fish remaining, but does significantly affect time to delayed mortality and to the 50 percent mortality level (Table 12). A comparison of days to 50 percent mortality for fish experiencing a maximum temperature of 24.0° to 26.9°C was made with time to 50 percent mortality for fish experiencing a maximum temperature of 27.0° to 29.9°C by means of the Mann-Whitney U-test (Sokal and Rohlf, 1969). The Mann-Whitney statistic (U) was 231, significant at the $P < 0.05$ level. Fish encountering higher maximum temperature reached the 50 percent mortality level significantly earlier (approximately 2 days) than those at lower maximum temperature. A similar analysis was done for the minimum temperature encountered (21.0° to 23.9°C vs 24.0° to 26.9°C). The Mann-Whitney statistic (U) was 236, significant at the $P = 0.025$ level. Fish encountering a lower minimum temperature reached the 50 percent mortality level significantly later (approximately 2 days) than those at higher minimum temperature.

Temperature appears to affect the shape of the mortality curve by increasing stress at higher temperatures and decreasing stress at lower temperatures, probably by influencing respiration and metabolic rate. The optimal range of temperature appears to be approximately from 21.0° to 24.0°C. The influence of temperature on survival may relate to the observation by fishermen that baitfish mortality occurs faster in summer than in winter.

5. Current. In Kaneohe Bay, nehu exhibited negative rheotaxis to currents originating from boat channels or streams emptying into the bay.

They maintained their position or swam against the current. They were also observed to mill in compact circles in shallow water near shore and to orient into currents and mill circularly in tanks and wells.

Swimming speed was determined to ascertain a current speed suitable for orientation while minimizing energy expended in swimming into supplemental current. The mean swimming speed which was determined from 25 trials was 0.17 m/sec (range = 0.15 to 0.20 m/sec, approximately 30 to 40 ft/min). The speed calculated probably represents a maximum since fish measured were large, acclimated, and swimming in a large pond. Newly captured fish confined in small tanks or wells probably swim more slowly. Current speed in excess of 0.13 m/sec (25 ft/min) was deleterious and increased mortality by stressing fish and buffeting them against tank walls. Current speeds were thus set lower than the maximum swimming speed determined above, usually at 0.10 m/sec (20 ft/min), or approximately 40 to 50 percent of the maximum range of swimming speed.

In laboratory tanks, the range of maximum current speed immediately in front of the current standpipe was from 0.05 to 0.20 m/sec (approximately 10 to 40 ft/min) with a mean of 0.10 m/sec (approximately 20 ft/min). Current speed varied from front to back and from top to bottom and was slower at the back and bottom of the tank. The range of current speed in barge wells was 0.08 to 0.13 m/sec (15 to 25 ft/min) with a mean of 0.10 m/sec (approximately 20 ft/min).

The effect of current on survival of nehu in captivity was tested in several experiments. In laboratory experiment 12 (Figure 15) mortality of fish in the tank given air only (Figure 15, curve B) occurred significantly earlier than in the tank with air and current (Figure 15, curve A). In the tank with current, 50 percent mortality was reached about 2 days later.

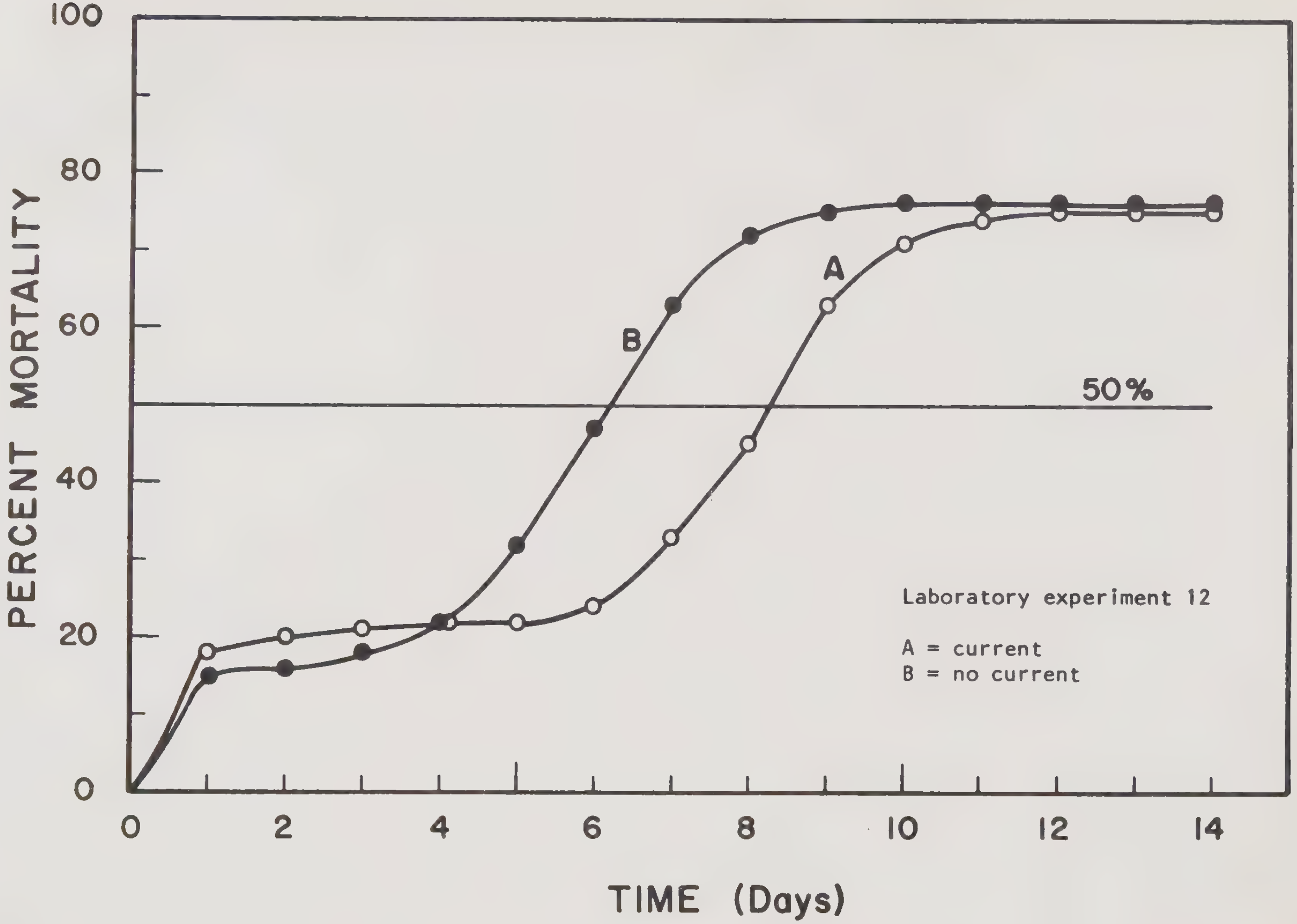


Figure 15. Effect of current on mortality of *S. purpureus*.

In laboratory experiment 13, various oxygen and current treatments were contrasted (Figure 13). Highest mortality occurred among fish given only air; lowest mortality occurred among fish given oxygen and current. Nehu given oxygen but not current survived nearly as well as those given oxygen and current, but delayed mortality began earlier (Figure 13, curve D). Fish given air and current underwent less mortality than those given air only, but mortality was higher than in fish given oxygen or oxygen and current. Provision of current altered survival primarily by postponing the onset of delayed mortality and the 50 percent mortality level. Current did not appear to decrease initial mortality or increase the number surviving by Day 14. Occasionally, initial mortality was higher when current was present, probably because weaker or injured fish were more quickly eliminated.

It was found best to maintain current throughout the experimental period. In laboratory experiment 15, the pump providing current was shut off on Day 6 in one tank (Figure 16, curve B); in another tank, current was left on for the entire 14 days (Figure 16, curve A). Mortality immediately increased in the tank where the current was shut off. Most observations showed that if current were shut off before the asymptotic mortality level were reached, mortality proportionately increased. Shutting off the current seemed to have little or no effect after asymptotic mortality was reached.

Milling behavior of nehu is influenced by current, oxygen concentration, and light. When no directional current is provided, nehu tend to move randomly during the first few days of captivity. The duration of random movement varies with oxygen concentration and severity of other environmental stress factors. If oxygen is maintained at saturation, random movement ceases and circular milling begins by the end of the first day.

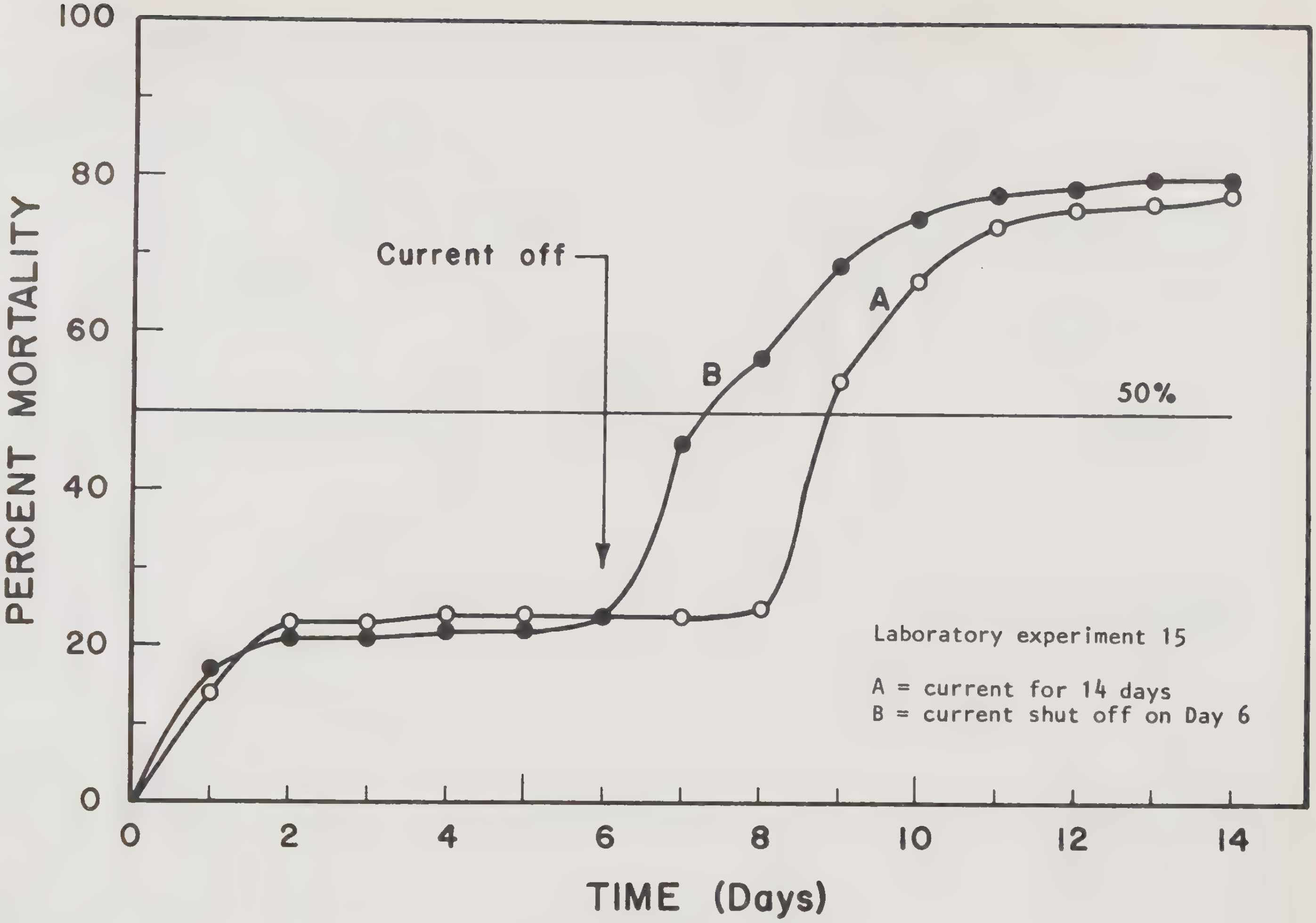


Figure 16. Effect of shutting off current on mortality of *S. purpureus*.

When directional current is added, fish immediately orient themselves to the current. Depending upon current strength and size and condition of fish, fish orient themselves to the current, maintaining a relatively stationary position for one or two days after capture. Thereafter, they begin milling in a complete circle. In most experiments the current was counterclockwise with the fish consequently swimming clockwise.

If the oxygen concentration fell below approximately 5.0 ppm or if other stress factors were severe, fish would mill more slowly at first and spread out to a less compact mill. As stress increases they move more randomly, eventually breaking up the mill. If severe stress were to continue, they would move randomly even if current were present. The mechanism by which current affects survival is not known, however postponement of delayed stress mortality may be due to one or all of the following reasons.

Current may provide a stimulus for immediate orientation when fish are placed in the unfamiliar and restricted capture situation. It probably requires some time for fish to learn visual cues and begin normal milling in small tanks. In the meantime they move randomly, often injuring themselves. This disorientation may also result in excessive energy demand. If current is provided, fish mill immediately, reducing such stress.

Nehu may need to swim at a certain speed in a uniform direction to maintain a sufficient flow of water past the gills. Provision of current and the instigation of milling increase the rate of oxygen availability to the gills, possibly increasing the efficiency of oxygen utilization.

Current appears to reduce the dissolved carbon dioxide concentration, possibly by increasing water turbulence.

6. Light and tank color. Nehu exhibit positive phototactic behavior. For example, during night baiting they are attracted to submerged lights

or will jump from unlighted tanks toward lights some distance away. Therefore, to keep fish milling normally at night a light must be provided over the tank. In early experiments light from windows at one end of the laboratory caused fish to aggregate at the end nearest the window. This difference in light intensity within the tanks interfered with normal milling and induced higher mortality. Therefore, several experiments varying color and intensity of light were conducted.

A major difficulty encountered in experiments measuring light intensity was the lack of available equipment to measure the effect of actual radiant energy on nehu. Attempts were made to equalize light intensity with a Gossen 7.67 to 510 foot-candle meter held approximately 1.25 cm above the water surface. Foot-candle measurements were converted to luminous units of lumen per square meter. It was realized, however, that the use of luminous units is inadequate for measuring the effect of light on organisms other than humans (Tyler, 1971).

Artificial fluorescent lights suspended 17.5 cm above the surface with variation in spectral outputs were also used. Different colors were found to vary characteristics of light penetration through the water column. The specifications of lights used in the experiments were: (1) G.E. F20T12-CW, 20 watts, cool white and (2) Westinghouse F20T12/G, 20 watts, green. The results of the experiments are considered only in terms of the relative effect of light color and intensity on mortality.

Loukashkin and Grant (1965) studied the behavior and reactions of the northern anchovy, *Engraulis mordax*, to different wave lengths of light and found that they prefer a particular wave length of green. It was observed that *S. purpureus* also appeared to prefer the same type of fluorescent green light. However, because measurements of intensity were inadequate, results were inconclusive.

A few experiments attempting to test the effect of green vs white light on survival were conducted. Results are somewhat confusing but generally indicate that green light may enhance survival if of sufficient intensity, particularly if no current is supplied to provide orientation. Results of laboratory experiment 16 are shown in Figure 17. Green lights were suspended over two tanks and white lights over two other tanks, all equalized to approximately 1,080 lumens/sq m (100 footcandles) at the surface. In tanks with white lights, fish did not mill circularly until Days 7 to 8. In all observations of milling which were made three times daily for 12 days, fish showed a mean of 65 percent random movement (no directional milling). Delayed mortality in these tanks began on Day 3; 50 percent mortality was reached by Days 3 to 4. In tanks with green lights fish began milling circularly immediately on Day 1. Observations for 12 days elicited a mean of 38 percent random movement, much less than in tanks with white lights. Delayed mortality in tanks with green lights did not begin until Day 4; 50 percent mortality was not reached until Days 5 to 6. In summary, there was about two days difference between the light treatments in the onset of delayed mortality. Green lights appear to promote normal orientation and milling, decrease stress, and increase survival.

Laboratory experiment 17 duplicated laboratory experiment 16, using the same lights and intensities, but adding current to the tanks. Fish under both light treatments began circular milling immediately on Day 1, probably because of the current. Figure 18 shows that there was no significant difference in mortality between tanks with green and white

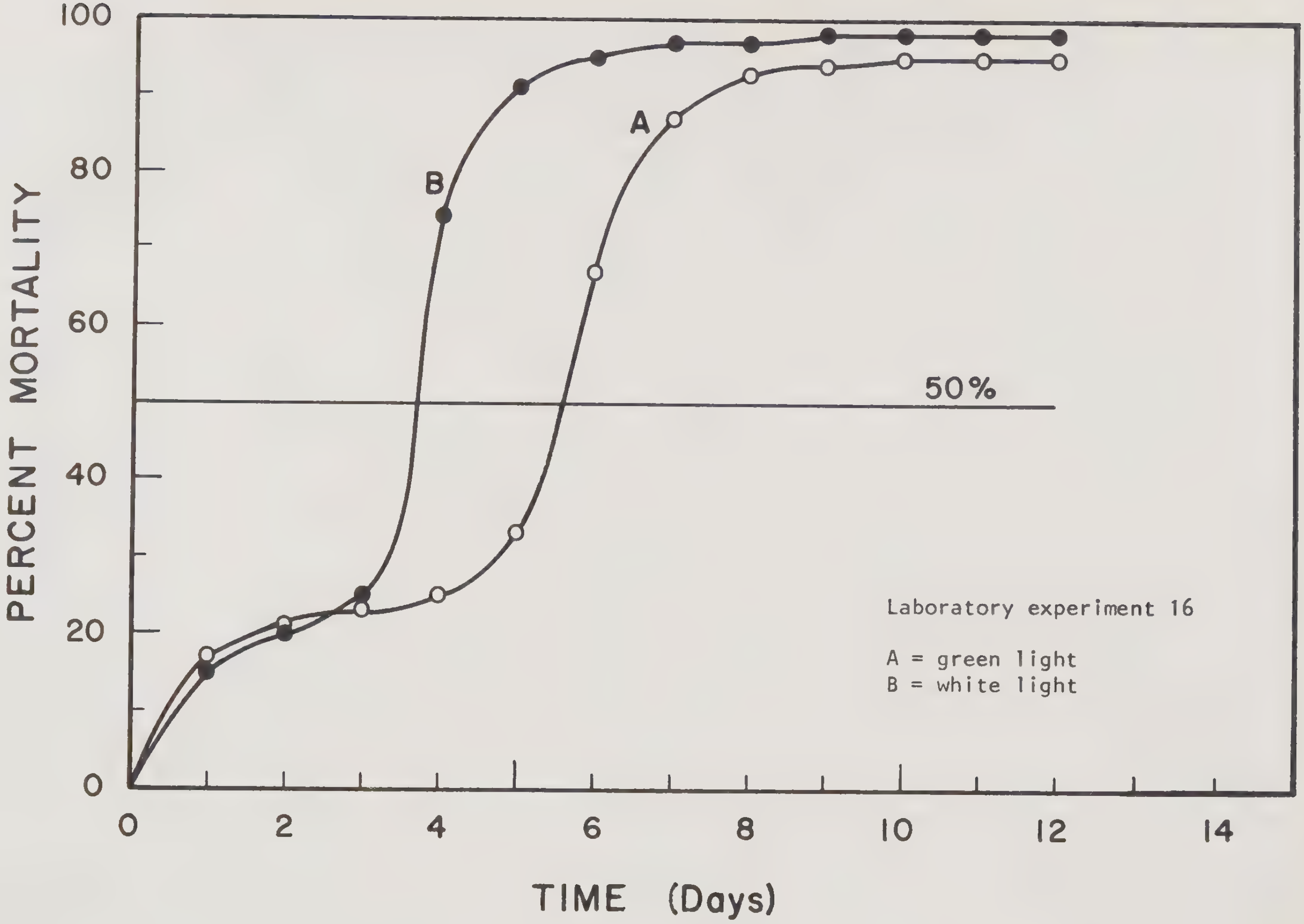


Figure 17. Effect of light color on mortality of *S. purpureus* in tank without current.

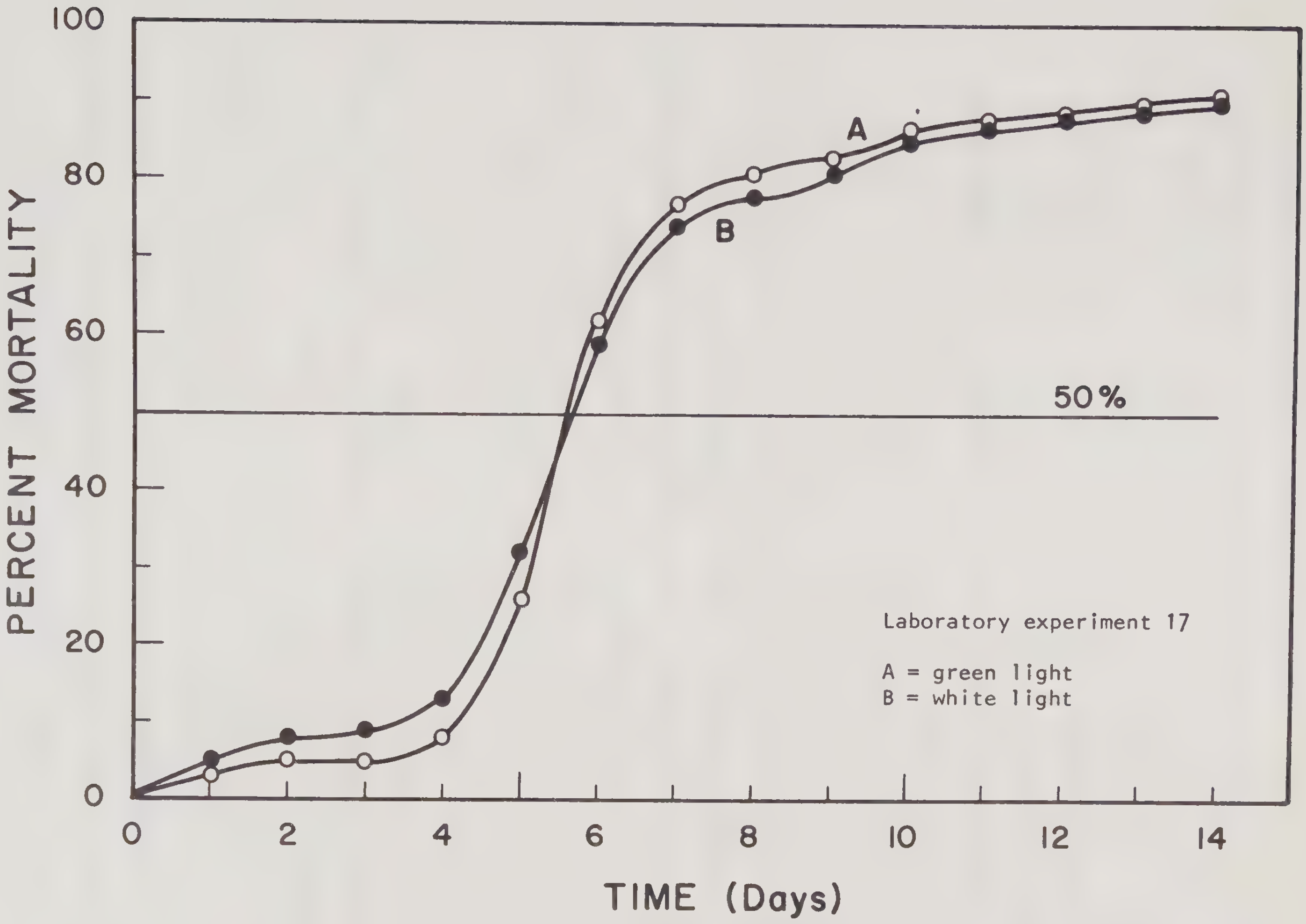


Figure 18. Effect of light color on mortality of *S. purpureus* in tank with current.

lights. A comparison of the two experiments indicates that light color significantly affects mortality only when there is no current for orientation. When current is present, it supercedes the effect of the light environment on orientation.

Following preliminary tests, new lights (Westinghouse F30T12/CW, cool white, 30 watts) were installed over each tank in an attempt to increase light intensity and uniformity. Variation occurred between tanks because of the irregular placement of ceiling lights. This variable is included in the general factor analysis of the concluding section. The correlation matrix of this analysis (Table 23) shows that increased light intensity significantly increases the time to onset of delayed mortality, time to 50 percent mortality, and percentage of survival. Increased variation of light intensity over the tank decreases percentage of survival, while higher and more uniform light intensity decreases mortality. The light intensity ranged from approximately 750 to 1,260 lumens/sq m (70 to 117 footcandles), averaging approximately 1,080 lumens/sq m (100 footcandles) at the surface. Measurements of light intensity taken again after 2 years 8 months show a substantial decrease in intensity of approximately 35 percent, indicating that lights should have been changed more frequently to maintain maximum possible intensity.

The effect of background color of the tanks was also tested. Visual environment was found to significantly affect orientation behavior, milling, and survival of nehu.

In all laboratory tanks the background color was green. On the barge, however, tanks in initial experiments were white. Since observations indicate that green was preferred by nehu, barge experiment 14 on contrasting tank colors was conducted (Figure 19). Experimental conditions were

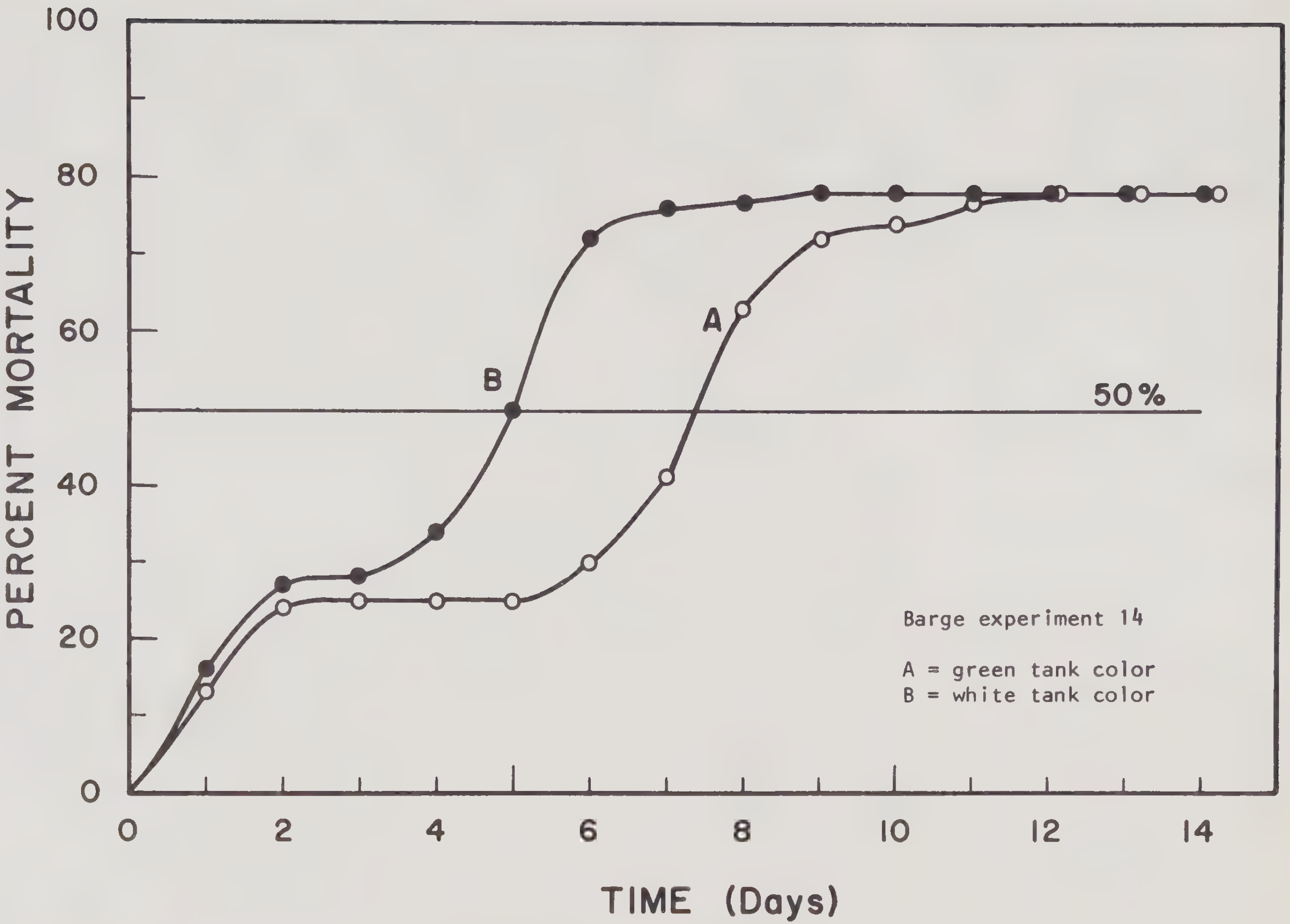


Figure 19. Effect of tank color on mortality of *S. purpureus*.

the same in both tanks, both being provided with oxygen and current. One tank was coated with white gel-coat resin, the other with green gel-coat resin (approximate color was Turquoise Blue, #25, #75 in *Webster's New International Dictionary of the English Language*, 2nd ed., 1961). Nehu in the white tank (Figure 19, curve B) underwent delayed mortality by Day 4 with 50 percent mortality being reached by Day 5. Fish in the green tank (Figure 19, curve A) did not undergo delayed mortality until about Day 6 and 50 percent mortality was reached by Day 7 to Day 8. Thus a significant difference of approximately 2-1/2 days in the onset of delayed mortality occurred between white and green tanks. A noticeable difference in milling behavior was also observed: fish in the green tank were more spread out and milled in a wider radius than those in the white tank.

Other experiments showed that nehu experience difficulty when orienting in black tanks; they move randomly and frequently hit the sides. The background color is therefore apparently important to normal orientation of fish. The closer the visual environment is to the range of maximum visual acuity, the sooner the fish probably orient to the capture environment.

Light experiments are incomplete. A means of measuring light in terms of radiant energy would be particularly desirable. A range of wave lengths of green light at various intensities should be tested to determine the optimal wave length and intensity of light for nehu. Also, in experiments, light was not varied on a diurnal basis. Lowering intensity gradually for the night and increasing again in the morning might enhance survival by affecting energy utilization and stress of fish.

Information so far indicates that the best visual environment for maximum survival is as follows: white or green light should be uniformly distributed over the tank at as high an intensity as is feasible--at least

1,080 lumens/sq m (100 footcandles) at the surface, optimally higher. At least some light should be provided at night, particularly if there is no current to provide orientation and especially during the first few days of capture when fish are adapting to the new environment. Light should not be turned on and off since it induces a startle reaction. The background color of the tank should be a light green-blue; dark colors should be avoided. Obvious visual cues on the sides of the tank may be used to assist in orientation.

7. Circulation--open system. In experiments with a continuous open system, an attempt was made to obtain the maximum turnover rate possible. In the laboratory, flow rate was limited by the line pressure of a gravity flow seawater system. On the barge, inflow was from Jabsco (barge experiments 1 to 10) or Jacuzzi (barge experiments 11 to 30) pumps. The objective was to maintain the highest flow and turnover rates possible without exceeding the optimal current speed (0.10 m/sec; 20 ft/min), which was controlled by valves in the current standpipe system.

The flow rate necessary to provide sufficient oxygen without addition of supplemental oxygen (assuming inflow water is at saturation) was calculated for an average bucket of fish (approximately 2,700 fish, weighing approximately 1,700 gm). The fish are assumed to be unacclimated, with an estimated mean rate of oxygen consumption of 1,270 cc per bucket of fish per hr $[2{,}700 \frac{\text{fish}}{\text{bucket}} \times 0.634 \frac{\text{gm}}{\text{fish}} \times 0.742 \frac{\text{cc/hr}}{\text{gm}}]$. Calculated flow rates in liters per hour are summarized in Table 36. Since the amount of oxygen at saturation varies with different temperatures and salinities, flow rates necessary to provide sufficient oxygen were calculated for the range of temperatures and salinities encountered under most experimental conditions (temperature, 20° to 30°C; salinity, 10 to 36 ppt).

The estimated flow rates (range = 205 to 285 liters/hr) are assumed optimal for the first day after capture when oxygen consumption is greatest. If the number of fish is more or less than one bucket, flow rate can be correspondingly increased or decreased. Further, after fish are acclimated (approximately 10 to 14 days) flow rate can be decreased. If supplemental oxygen is provided, flow rate can be decreased, but the possible accumulation of toxic metabolites must be considered if water exchange is too slow.

For most laboratory experiments the water inflow valve was not fully open and higher flow rates were possible if there were sufficient line pressure in the seawater system. The flow rate in most laboratory experiments ranged from 0.07 to 0.11 liter/sec (1 to 2 gal/min), with a mean flow of 0.08 liter/sec (1.3 gal/min). The percentage of the turnover rate for the 180-gal tanks ranged from 37 to 58 percent per hour, the mean turnover rate being 42 percent per hour. The presence of Cuno filters (Cuno Engineering Corporation, Filter No. P110) in the inflow line (Plate 15) decreased flow rate very slightly when filters were clean. When filters were clogged, the flow rate greatly decreased, so they were regularly replaced. For most experiments, filters were not used.

Table 36 shows that the flow rate necessary to supply 1,270 cc oxygen/hr to an average bucket of fish ranged from 205 to 285 liters/hr (54 to 75 gal/hr). The average flow rate in the laboratory (288 liters/hr or 76 gal/hr) therefore was adequate to supply sufficient oxygen for low to average densities of fish. If stress were excessive and densities higher, however, the flow rate would have been insufficient to provide necessary oxygen. Also, for many experiments line pressure was low, resulting in reduced flow rates. Under most experimental conditions supplemental oxygen was added to ensure oxygen saturation.

In initial barge experiments (1 to 10), circulation inflow was provided by Jabsco pumps, one pump per 1,000-gal well. The flow rate ranged from 0.28 to 0.36 liter/sec (4 to 6 gal/min), with a mean flow rate of 0.30 liter/sec (4.8 gal/min). The percentage of turnover of the 1,000-gal well ranged from 27 to 34 percent per hour, with a mean of 28 percent per hour. It required a flow rate of 205 to 285 liters/hr (over the experimental temperature-salinity range) to provide 1,270 cc oxygen/hr for one bucket of fish. The number of buckets in barge wells ranged from five to ten. The flow rate required for sufficient oxygen was from 1,025 to 1,425 liters/hr for 5 buckets and from 2,050 to 2,850 liters/hr for 10 buckets. The Jabsco pump with a flow rate of 1,010 to 1,300 liters/hr was sufficient to provide oxygen for approximately 5 buckets of average-sized fish, but insufficient for 10. Thus, densities greater than 5 buckets per 1,000 gal required supplemental oxygen.

A 1 hp Jacuzzi pump (Plate 2) was used in later barge experiments (11 to 30). The flow rate to each well ranged from approximately 0.57 to 0.64 liter/sec (9 to 10 gal/min) with a mean of 0.60 liter/sec (9.5 gal/min). The turnover rate of each well was from 54 to 60 percent per hour, with a mean of 57 percent per hour or slightly more than one complete turnover in 2 hours, and is sufficient to provide oxygen for respiration for about 10 buckets of average-sized fish.

Optimal flow rate will vary with temperature, salinity, availability of supplemental air or oxygen, size of fish, and severity of stress and must be determined anew for each experiment. Eventually, however, the maximum flow rate possible should be selected while simultaneously maintaining an optimal current speed.

8. Circulation--closed system with reduced salinity. Previously described experiments show that reduced salinity (40 to 50 percent seawater; 16.0 to 18.0 ppt) is the most significant factor in decreasing stress and subsequent mortality of nehu in captivity. Constant open circulation of 50 percent seawater renders highest survival, but fishing vessels do not carry sufficient fresh water for this to be feasible at sea. If, however, 50 percent seawater is recirculated for at least 3 hours after capture (period of severest osmoregulatory stress), survival is greatly increased. This treatment might be possible on fishing vessels when in port.

Experiments were done to find the maximum time fish could be exposed to recirculated 50 percent seawater before accumulation of metabolites and other stress factors induced excessive mortality. Factors determining the length of this period are density, accumulation of scales, mucus and other organic material, carbon dioxide with decrease in pH, and ammonia. In all experiments with closed systems, oxygen was kept at saturation and current was provided.

In preliminary experiments 50 percent seawater was recirculated in a closed system until fish began dying. After a few hours water became murky and brown, attaining a strong "fishy" odor. Fish initially showed stress by decreasing milling speed and spreading out from the normal mill. They eventually lost orientation to current and began darting or jumping randomly. Finally, they sank to the bottom and died. Figure 20 illustrates results of laboratory experiment 30 in which 50 percent seawater was recirculated for about 9 hours before the system was opened to a continuous flow of 100 percent seawater. There was no supplemental treatment of buffering or filtering. A bucket of nehu (approximately 2,781 fish; 1,427 gm) was placed in the 180-gal laboratory tank (1,550

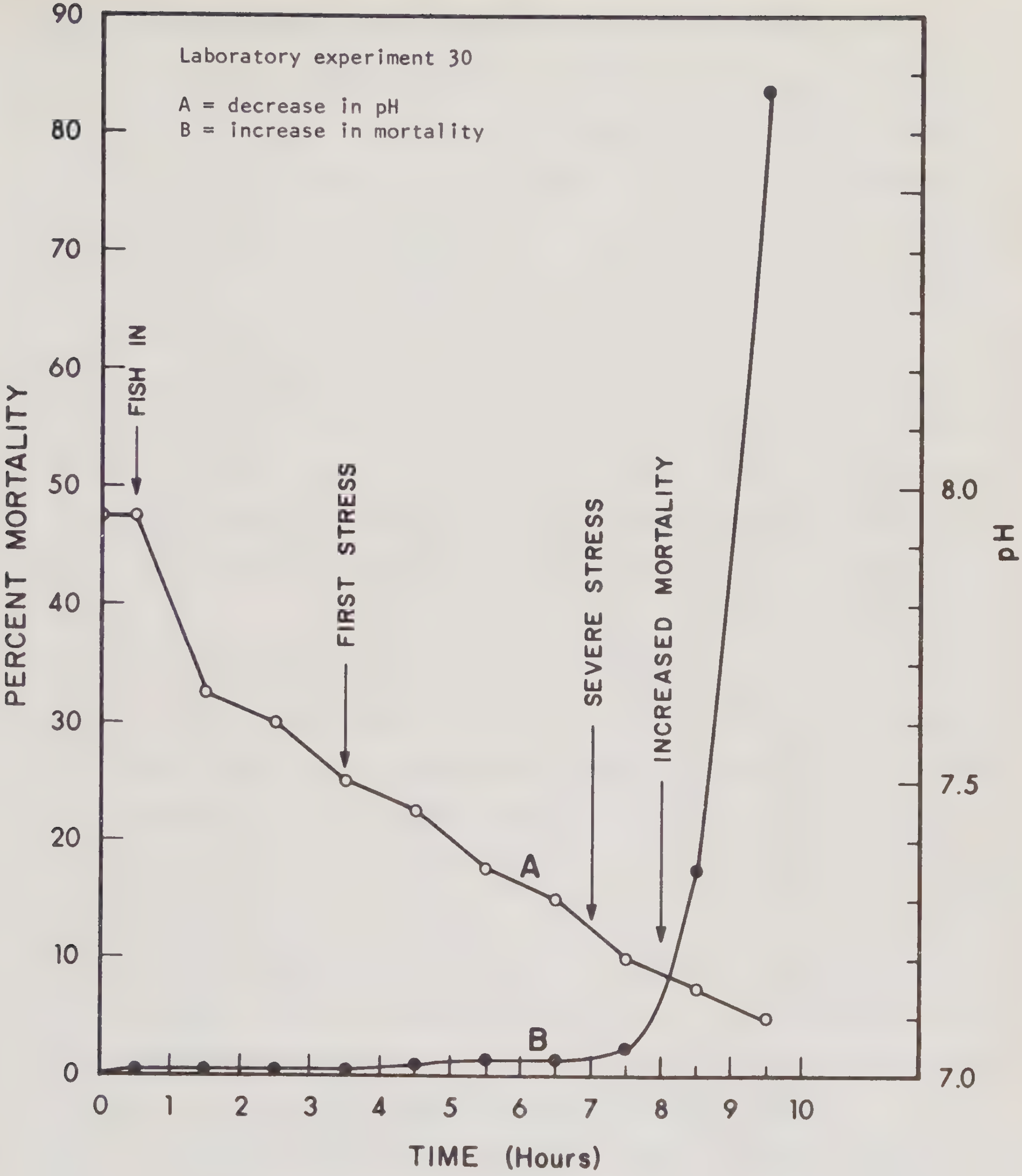


Figure 20. Effect of reduced salinity on mortality of *S. purpureus* and reduction of pH in closed system recirculated for 9-1/2 hours.

fish per 100 gal; 793 gm per 100 gal). Figure 20 shows hourly decrease in pH Figure 20, curve A) and increase in mortality (Figure 20, curve B). The first symptom of stress, exemplified by alteration of normal milling pattern, was observed at pH 7.50. Obvious stress, indicated by erratic and random swimming, was observed at pH 7.25, about 6-1/2 hours after the experiment began. Mortality did not increase until after 7 to 8 hours at pH 7.20 to 7.15; thereafter, mortality occurred rapidly. After 9 hours, the system was opened to 100 percent seawater. By that time pH had decreased to a minimum of 7.10. It is obvious from the daily mortality curve for this experiment (Figure 21) that the system was closed too long. Death was probably primarily due to accumulation of carbon dioxide and reduction of pH. Other factors probably contributing to mortality were accumulation of ammonia and suspended organic matter.

Barge experiment 18 was conducted under similar conditions as laboratory experiment 30 above, except that the system was closed for a shorter period. The density of fish was equivalent to that in the above experiment (725 gm per 100 gal). In this experiment, 50 percent seawater was recirculated for only 4 hours, or until pH decreased to 7.55; then the system was opened to 100 percent seawater. The daily mortality curves of Figure 22 show that mortality was significantly less in the tank with 4 hours of recirculated 50 percent seawater (Figure 22, curve A), than in the control tank with 100 percent seawater in an open system (Figure 22, curve B). In the recirculated tank, only 11 percent of the fish were dead by Day 6 and 46 percent by Day 11. The 50 percent mortality level was not reached by Day 14.

Additional experiments demonstrate that even brief exposure to recirculated 50 percent seawater (3 to 4 hours) substantially increases survival

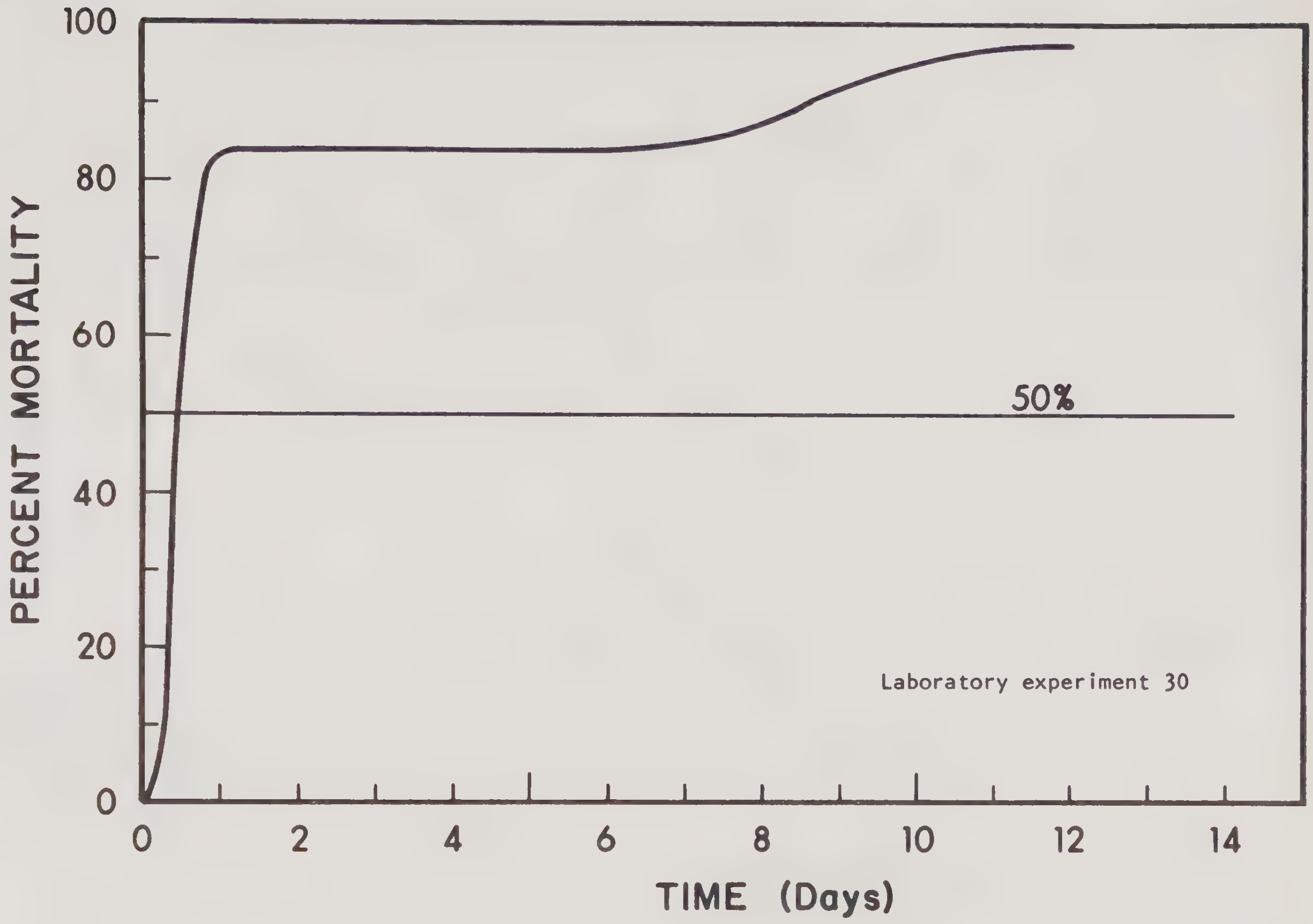


Figure 21. Effect of reduced salinity on mortality of *S. purpureus* in closed system recirculated for 9-1/2 hours on Day 1.

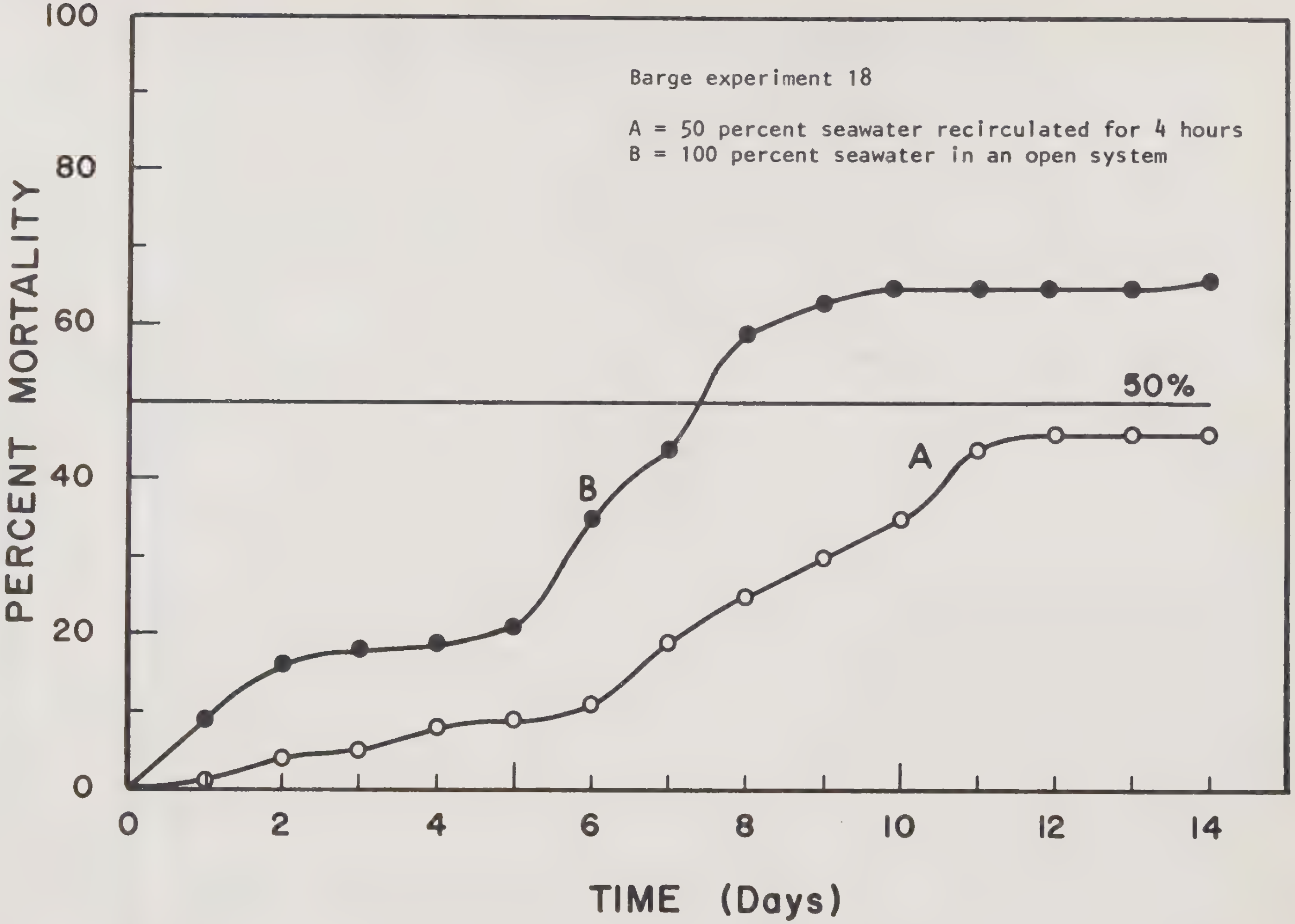


Figure 22. Effect of reduced salinity on mortality of *S. purpureus* in closed system recirculated for 4 hours.

by reducing osmoregulatory stress during the critical first few hours after capture, as long as pH does not fall below 7.5. To maintain 3 or more hours of exposure to recirculating 50 percent seawater, the density of fish must be controlled since the decrease in pH is related to density: if too many fish are crowded into tanks or bait wells, carbon dioxide accumulates and pH decreases too rapidly.

Table 13 summarizes data for experiments with recirculated 50 percent seawater (no supplemental treatment of buffering or filtering). An example of pH decrease with time is shown in Figure 20 (curve A). Results show that pH usually decreases rapidly during the first 2 hours after capture, then decreases linearly. Data show a significant fit to curvilinear regression ($\hat{Y} = 1/a+bX$) with a range in $\underline{b}$ = 3.250 to 11.003 ($X\ 10^{-5}$). The coefficient for linear regression ($\underline{b}$) in Table 13 indicates a rate of pH decrease to 7.5 of approximately 0.001917 to 0.006611 pH points per minute (0.11 to 0.40 pH points/hr).

The time for pH to decrease to 7.5 ranged from about 80 to 200 minutes (approximately 1-1/3 to 3-1/3 hours), depending on density in gram wet weight per 100 gal (Figure 23). The linear regression coefficient ($\underline{b}$) is 0.13636 minute per gram wet weight. Figure 23 shows that to recirculate 50 percent seawater in a closed system for 3 hours without excess stress and mortality due to pH decrease and without supplemental buffering treatment, the concentration of nehu should be about 750 gm wet weight of fish per 100 gal of seawater.

In experiments with open systems circulating 100 and 50 percent seawater continuously, pH occasionally decreased to a limiting value of 7.5 when the density of fish was great or flow rate too slow. This occurred on Day 1, when density exceeded 1,000 gm wet weight per 100 gal.

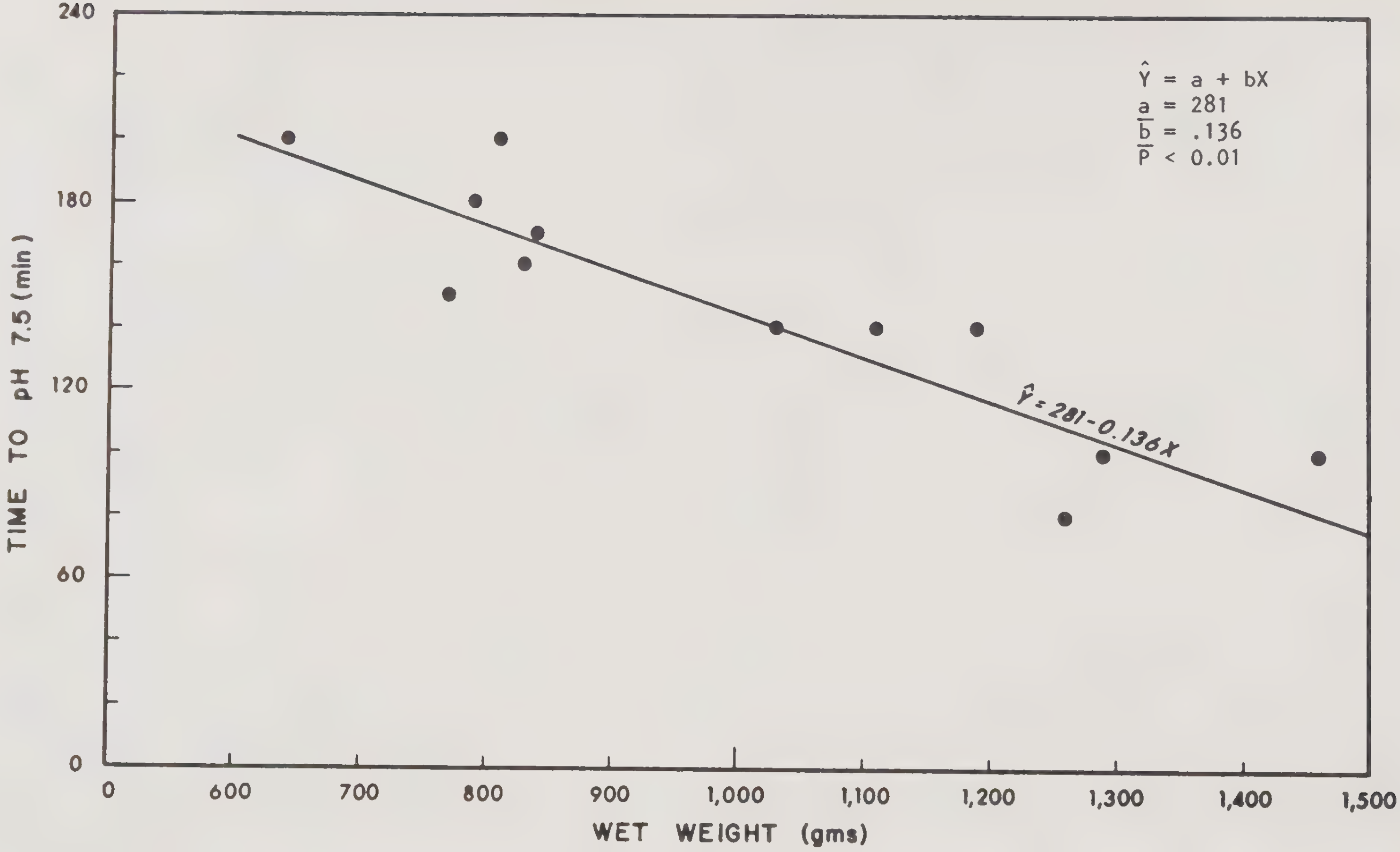


Figure 23. Time for pH to decrease to critical level of 7.5 for different densities of *S. purpureus* in closed system.

To avoid this stress, density in an open system should not exceed 1,000 gm per 100 gal or the flow rate should be increased, at least for the first day after capture.

In closed systems or recirculating 50 percent seawater, mucus, scales, feces, and other organic matter accumulate and probably impede respiration. To test the effect of the removal of such material on survival, a protein skimmer was added (Plates 13 and 14). The protein skimmers used were enlarged and modified from the original German design (Sander Brand, 500, made in Germany). Water was pumped through the skimmer, pulling water from the top to the bottom, while air was simultaneously fed into the bottom. Organic material adhered to rising air bubbles to create a foam at the surface which was trapped in the top section of the skimmer and removed.

The effect of adding a protein skimmer to reduce mortality was significant. Figure 24 shows the results of laboratory experiment 32 in which one tank had a protein skimmer and in the other, none. Fifty percent seawater was recirculated through both tanks for approximately 5 hours when pH was just above 7.5, then the system was opened to 100 percent seawater. Mortality in both tanks was low because of reduced salinity, but in the tank with no protein skimmer (Figure 24, curve B), 50 percent mortality occurred by Days 11 and 12, while in the tank with the protein skimmer (Figure 24, curve A), mortality was significantly less throughout the entire experiment and the 50 percent mortality level was never reached.

In barge experiment 19 (Figure 25), a significant difference in mortality was apparent between fish in the tank with a protein skimmer (Figure 25, curve A) and fish in the tank with no protein skimmer (Figure 25, curve B). Fifty percent seawater was recirculated in both tanks for 4 hours 40 minutes

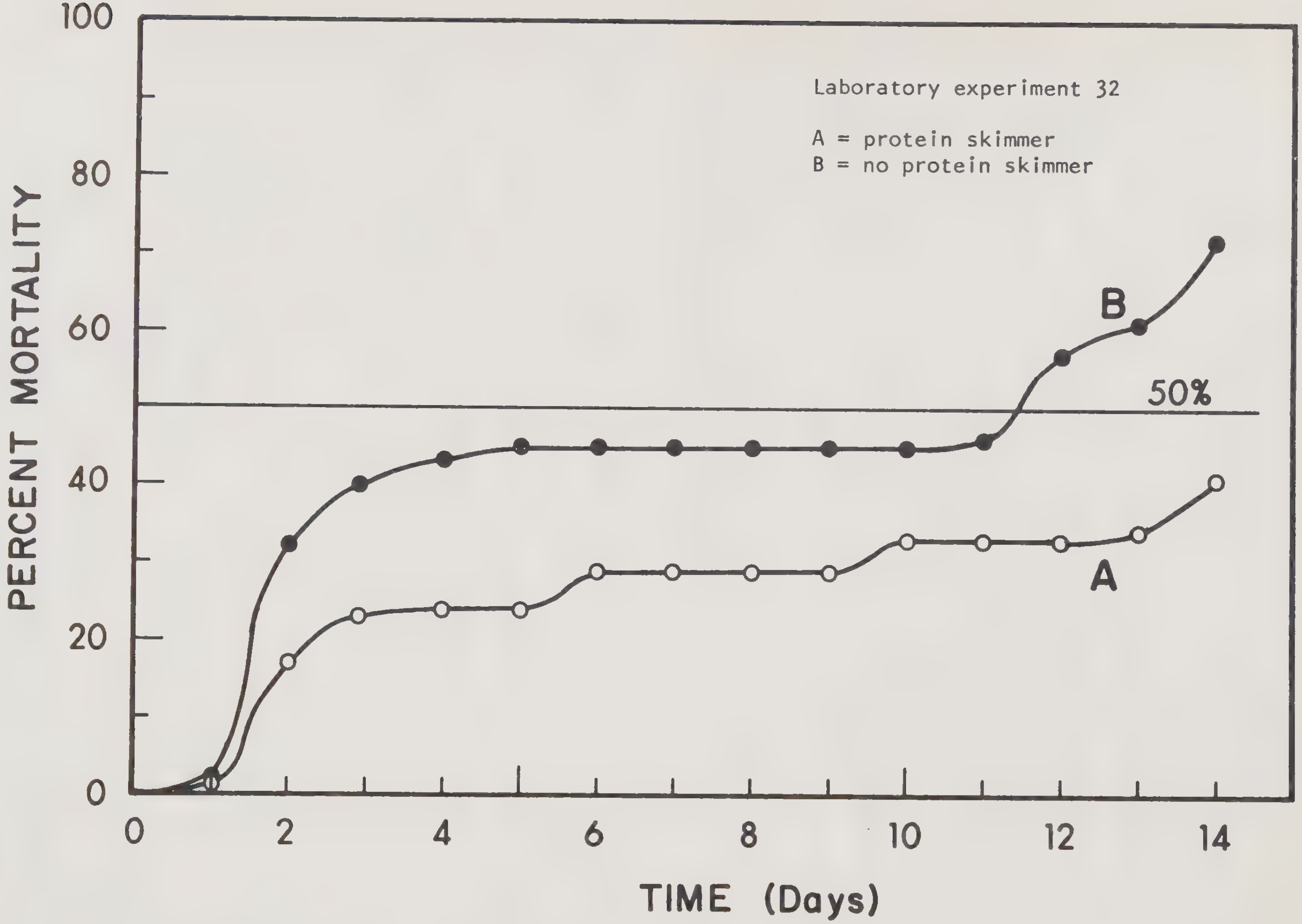


Figure 24. Effect of protein skimmer and reduced salinity on mortality of *S. purpureus* in closed system recirculated for 5 hours.

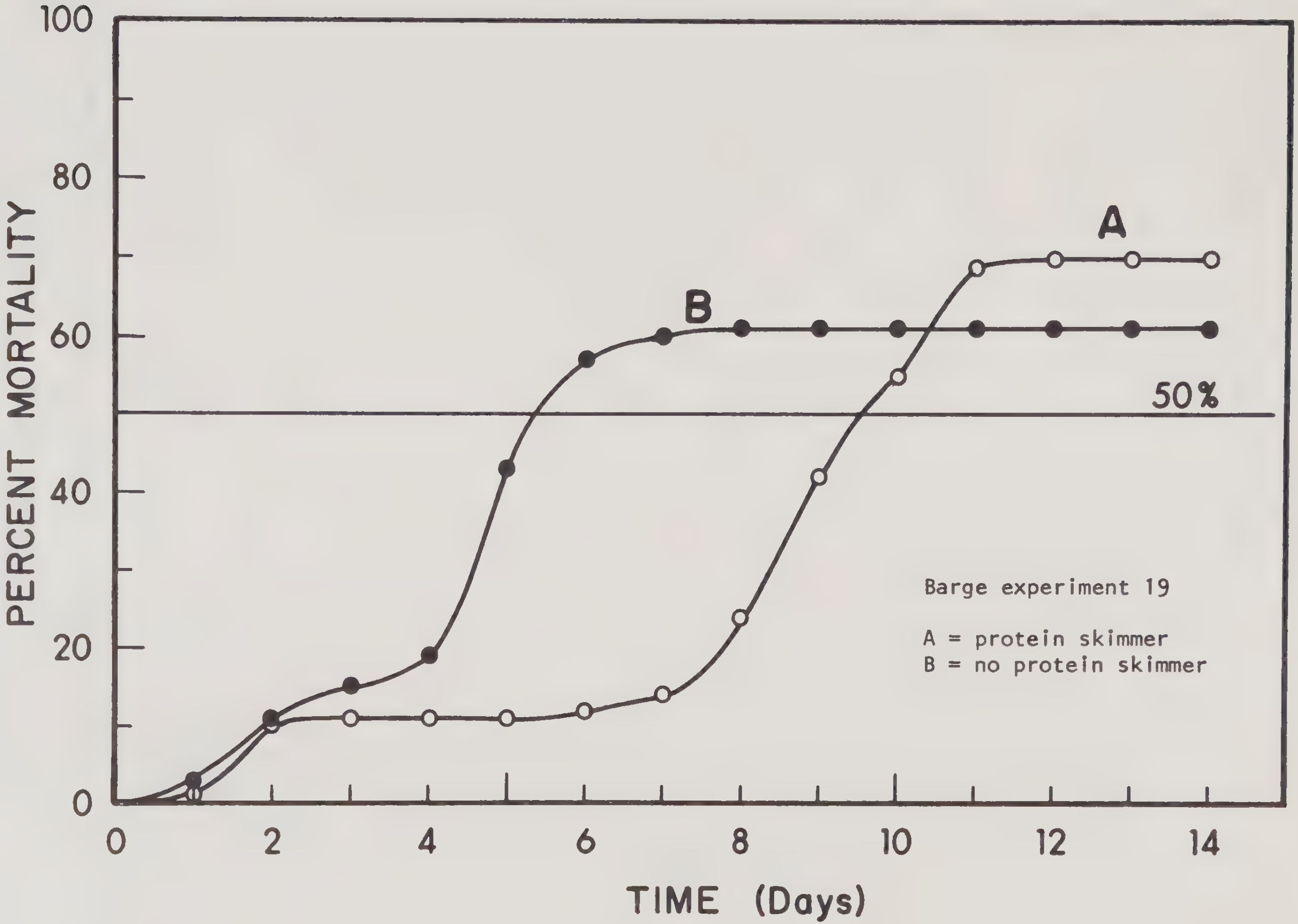


Figure 25. Effect of protein skimmer and reduced salinity on mortality of *S. purpureus* in closed system recirculated for 4 hours 40 minutes.

or until pH was just above 7.5. In the tank without the protein skimmer, 50 percent mortality was reached by Days 5 to 6, while in the tank with the protein skimmer 50 percent mortality was not reached until Days 9 to 10, a difference of approximately 4 days. The pH drops rapidly even when a protein skimmer is present, indicating that it has little effect in decreasing the accumulation of carbon dioxide.

Experiments were then conducted to determine if controlling pH by means of buffers would allow an increase in recirculation time. An amine buffer--Trizma 8.3 (McFarland and Norris, 1961)--was used, Several concentrations were tested: 2 gm/gal of 50 percent seawater was found sufficient to maintain pH of 8.0 to 8.3 for 24 hours at mean densities. In laboratory experiment 34, Trizma buffer was added to one tank (Figure 26, curve A) and not to another (Figure 26, curve B). Both tanks were given supplemental oxygen and current, but no protein skimmer. In the tank with no buffer, pH dropped rapidly to 7.5 in only 1 hour 20 minutes; the system was then opened to 100 percent seawater (Figure 26, curve B). The tank with buffer showed almost no decrease in pH after 9 hours of recirculation when the system was opened to 100 percent seawater (Figure 16, curve A). Mortality in both tanks was relatively high, but mortality curves showed some difference. The tank with buffer reached 50 percent mortality by Days 6 to 7, approximately 1 day after the tank with no buffer (50 percent mortality by Days 5 to 6). Since other toxic substances (e.g., ammonia) accumulated during the recirculation period, it is probable that survival in the buffered tank would have been greater if the recirculation period had been decreased.

In another experiment both buffer and a protein skimmer were tested. Laboratory experiment 36 (Figure 27) showed that although buffer and skimmer were present and pH did not decrease significantly, mortality is still high

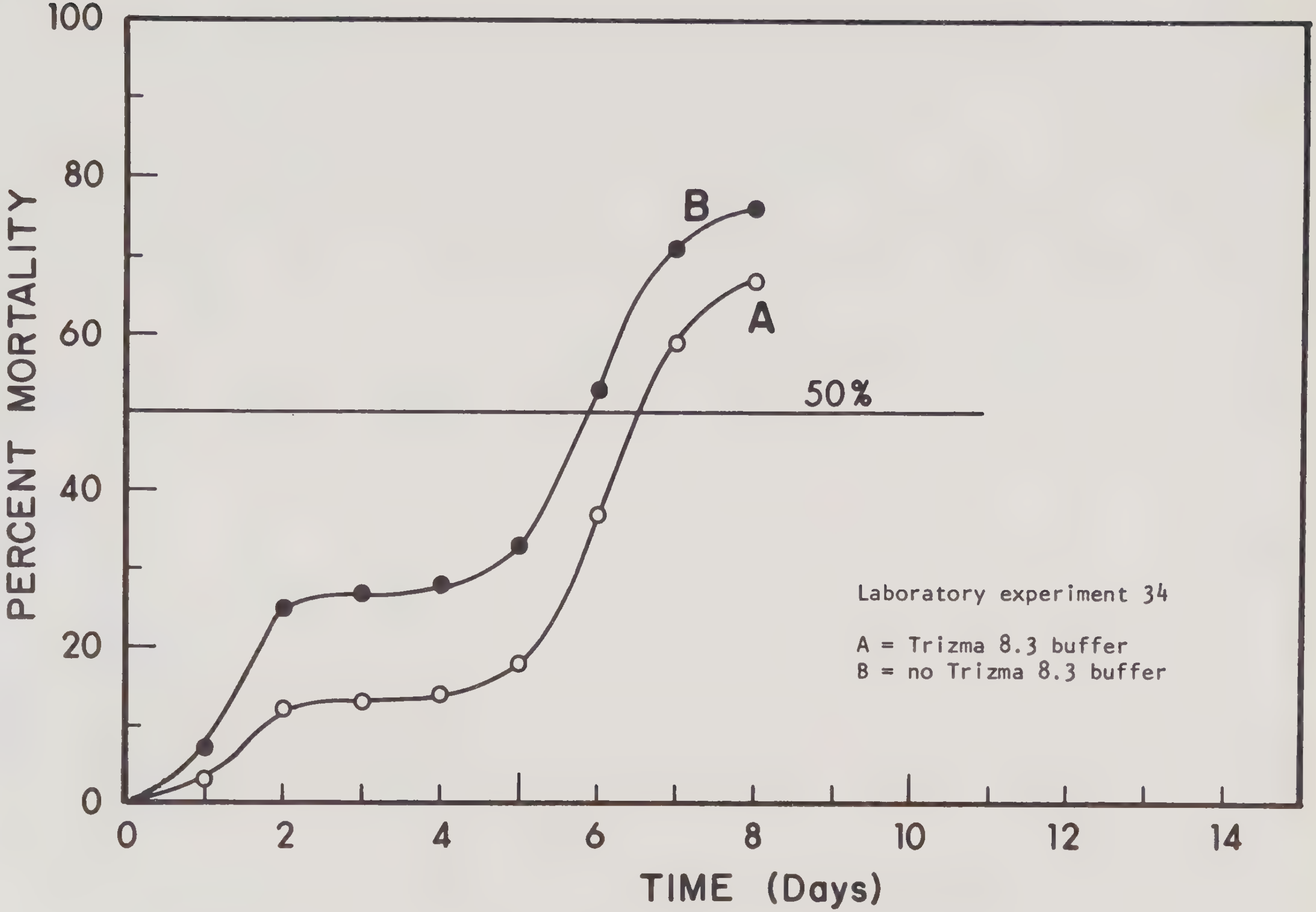


Figure 26. Effect of Trizma 8.3 buffer and reduced salinity on mortality of *S. purpureus* in closed system recirculated for 9 hours.

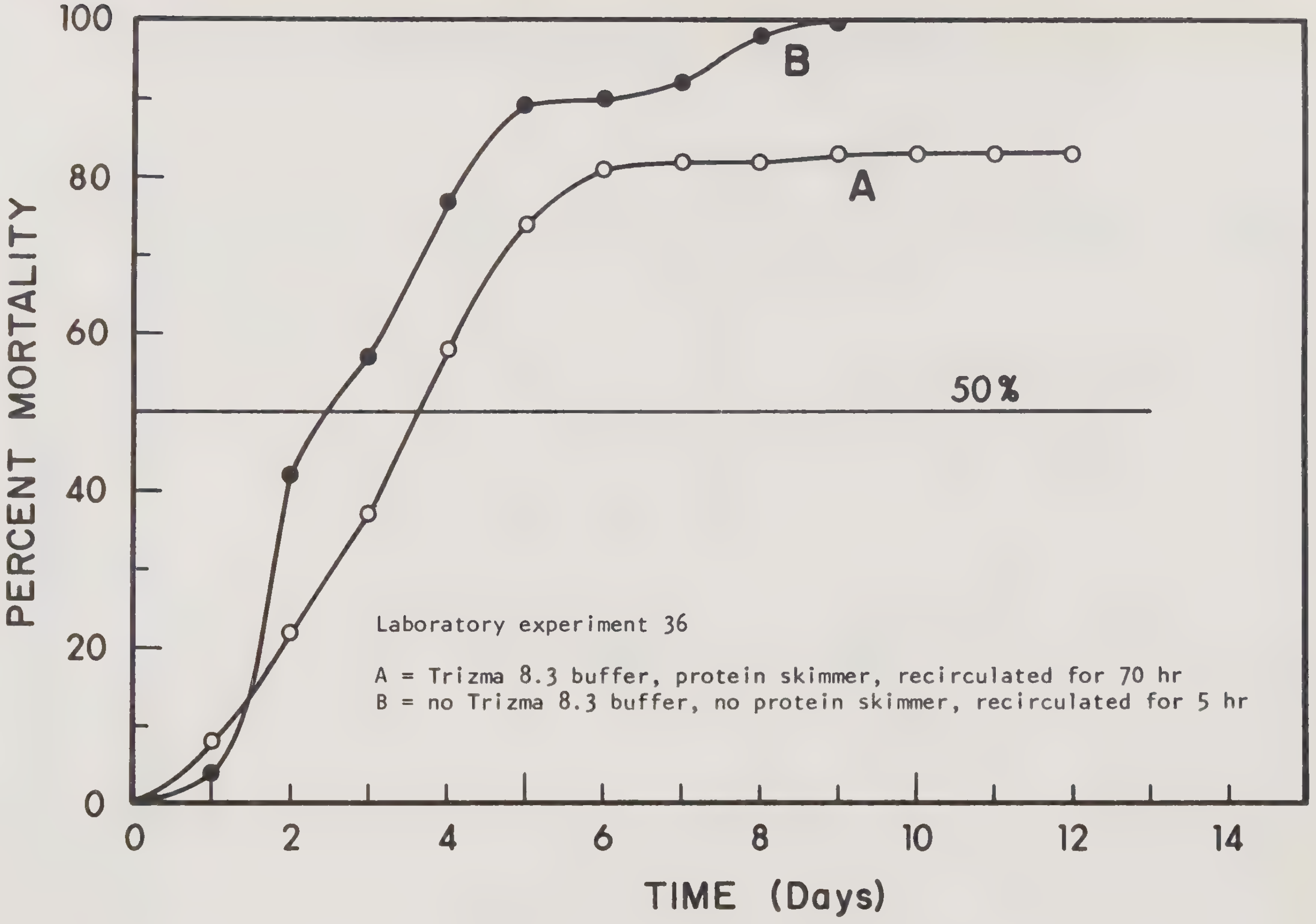


Figure 27. Effect of Trizma 8.3 buffer, protein skimmer, and reduced salinity on mortality of *S. purpureus* in closed, recirculated system.

in a closed system when 50 percent seawater is recirculated too long. Water in the tank with buffer and skimmer was recirculated for 70 hours; the pH only decreased to 7.90 (Figure 27, curve A). The tank with no buffer and skimmer was recirculated for 5 hours; the pH decreased to 7.45 (Figure 27, curve B). Fish treated with buffer and skimmer exhibited slightly higher survival, but fish in neither tank benefited greatly from recirculated 50 percent seawater. High mortality in the tank with buffer and skimmer was probably due to accumulation of toxic metabolites such as ammonia. In the tank with no additional treatment, pH was allowed to decrease below 7.50.

In conclusion, it seems best to recirculate water for no more than 3 to 4 hours (at appropriate density; Figure 23), regardless of addition of buffer or protein skimmer. Further, Trizma 8.3 buffer may maintain too high a pH, thereby increasing the accumulation rate of ammonia. A better treatment may be to use a buffer of lower pH. Further experimentation is needed to clarify this point.

9. Metabolites. Metabolites possibly affecting stress and mortality of nehu in the experiments are carbon dioxide and ammonia. In open systems with optimal environmental conditions (i.e., low density of nehu, oxygen saturation, and maximum turnover rate), it is unlikely that either metabolite will reach stress or toxic levels. Table 14 shows that in laboratory experiment 37, dissolved carbon dioxide concentration in nehu tanks with circulation, current, and supplemental oxygen or air did not significantly exceed that of water inflow control. The maximum carbon dioxide concentration measured over the 7-day experimental period was in tanks with circulation and air only (4.6×10^{-2} millimoles per liter; 2.12 ppm; partial pressure = 1.16 mm Hg). From these data, it would appear that

current may decrease carbon dioxide concentration. All concentrations of carbon dioxide were probably below a toxic level, but over a longer period of exposure this concentration might induce stress by affecting respiration. Unfortunately, it was not feasible to measure carbon dioxide concentrations daily. In some experiments with suboptimal environmental conditions, carbon dioxide may reach stress levels even in open systems. This is indicated by a few such experiments with low pH values (7.5 to 7.9). Further, in closed-system recirculated brackish water, carbon dioxide did accumulate, inducing stress and mortality.

Attempts to measure ammonia, which affects both stress and mortality in closed systems, were unsuccessful. Further experimentation and measurement are required to clarify the effect of carbon dioxide and ammonia on nehu in closed systems.

10. Density. Each experiment must be evaluated individually to determine suitable density. The optimum varies with (1) volume of water, (2) size of fish, (3) turnover rate, and (4) environmental factors such as oxygen, current, and visual environment.

Figure 28 summarizes data from three comparable experiments which vary the density of fish. Tanks were provided with supplemental air only, the current flow rate was 0.08 liter per second, and salinity was 34.0 to 36.0 ppt. Air was insufficient to maintain oxygen saturation and on Day 1, oxygen concentration fell to a stress level. Initial mortality was independent of density: most fish died from handling injuries and not from environmental stress effects. Further, time to delayed mortality and the 50 percent mortality level did not vary significantly between tanks of different concentrations, indicating that fish undergo stress mortality at the same time regardless of initial density. By Day 14, however, a greater percentage of

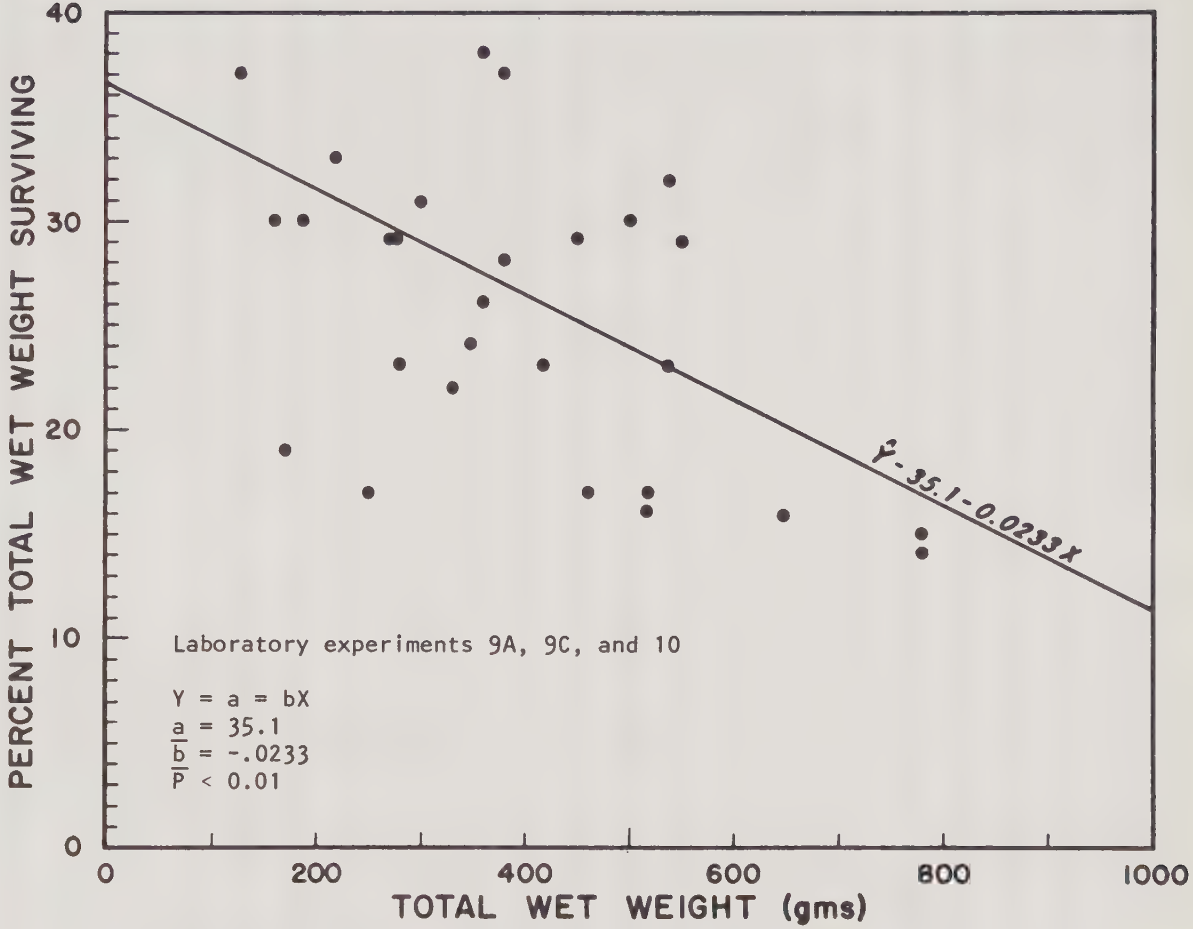


Figure 28. Effect of initial density on mortality of *S. purpureus*.

fish survived in tanks with lower initial density. Figure 28 shows that the relationship between percentage of survival to Day 14 and initial density in gram wet weight is approximately linear ($\underline{b} = 2.3343 \times 10^{-2}$; $P < 0.01$).

In Table 15, three capture environments are described and the approximate density of nehu appropriate for each is estimated. These estimates are based on groups of fish of mean wet weight from 0.500 to 0.700 gm. In bait wells with poor conditions (Table 15, item A) and a minimum turnover rate of about 25 percent per hour, density of fish is usually oxygen-limited. In this case, density should be approximately 80 to 130 gm per 100 liters. If bait well conditions are improved (Table 15, item B), density can be increased to about 130 to 260 gm per 100 liters. If 50 percent seawater is recirculated for 3 hours to give best conditions (Table 15, item C), density must be regulated to 200 to 210 gm per 100 liters or pH decreases to a lethal level too rapidly and other metabolites may reach stress or lethal concentrations. Density of fish in 50 percent seawater in an open system can be increased above that of a closed system. Densities in Table 15 are based on a minimum turnover rate (25 percent per hour). If flow rate is increased in items A and B (Table 15), density can be proportionately increased. If fish are injured from handling or if other environmental stress is great, densities should be decreased.

Results of all experiments (with supplemental oxygen available) indicate that, to a maximum density of approximately 260 gm per 100 liters (1,000 gm per 100 gal), density does not significantly affect the shape of the mortality curve if oxygen is at saturation in an open system. Greater densities proportionately increase mortality. Crowding fish at high densities would therefore simply result in additional work in removing dead fish.

11. Food. Juvenile and adult nehu usually feed on the dominant crustacean zooplankton. In Kaneohe Bay these are primarily copepod adults, nauplii, and eggs (Hiatt, 1951). On most fishing vessels where nehu are used as baitfish within a few days, feeding is unnecessary and probably undesirable. Food is costly and pollutes well water and nehu reduce the oxygen level more rapidly when feeding. Lack of food does not increase mortality until about 10 to 14 days after capture.

Because some experimental objectives require keeping nehu for longer periods, effects of various food treatments on survival and weight maintenance were contrasted. Experiments indicate that, of the various dried commercial fish meals, ground liver, ground skipjack tuna, Oregon moist pellet (OMP), and frozen brine shrimp (FBS), frozen brine shrimp elicit optimal feeding behavior and best weight maintenance.

Nehu prefer brine shrimp, feeding on them earlier than any other food tested. They also feed on Oregon moist pellet if sufficient time is allowed for training. Most difficulty with foods other than brine shrimp is behavioral. Nehu are slow to feed on dried or ground food, accepting it only after several days of training. Also, much dried or ground food is wasted: when missed by the fish, it falls to the bottom of the well and becomes a contamination problem.

How soon nehu begin feeding in captivity depends not only on food type, but also on the condition of the fish. Just after capture, when fish are stressed or injured, few will feed. If environmental conditions are good, a small percentage of nehu begin feeding on Day 2. The first significant feeding response usually begins on Day 3. About 25 percent of the fish feed at this time; the percentage gradually increases until most are feeding by Days 5 to 6. When delayed stress mortality begins, feeding activity again decreases, although most fish continue feeding unless stress is excessive. After the asymptotic level of mortality is reached, fish feed readily for the remainder of the experimental period. In most experiments feeding began on Day 3 or Day 4 and the amount of food was decreased when fish were stressed or died.

Ideally, nehu should be fed several times daily, but experimental conditions limited the feeding schedule to 3 times daily. If fed more frequently, fish would learn to accept food earlier and less would be wasted. As noted, the amount of food varied daily, but the wet weight of food averaged 36 percent of the wet weight of nehu; dry weight of food averaged 3 to 5 percent of the wet weight (Table 16). The percentages of dry weight of brine shrimp and moist pellet are in Table 17.

In laboratory experiment 1 (Table 18; Figure 29), five food treatments were contrasted using acclimated fish (22 days). There was no significant difference in mortality between food treatments until approximately Day 10, when the effects of starvation increased mortality slightly in fish given no food (Figure 29, curve B) or only plankton (Figure 29, curve A). No significant increase in mortality was observed in fish fed trout food only (Figure 29, curve D), trout food plus frozen brine shrimp, or frozen brine shrimp only (Figure 29, curve C). Figure 30 shows the calculated regression curves (dry weight of a given standard length) at the end of 14 days for nehu given different food treatments. When treatment regressions were compared with the regression curve of the initial sample (Figure 30, curve E), the results showed that fish given trout food plus frozen brine shrimp or frozen brine shrimp only (Figure 30, curves B and C) increased in dry weight. Those fed trout food only gained somewhat less weight (Figure 30, curve D); those fed plankton or no food (Figure 30,

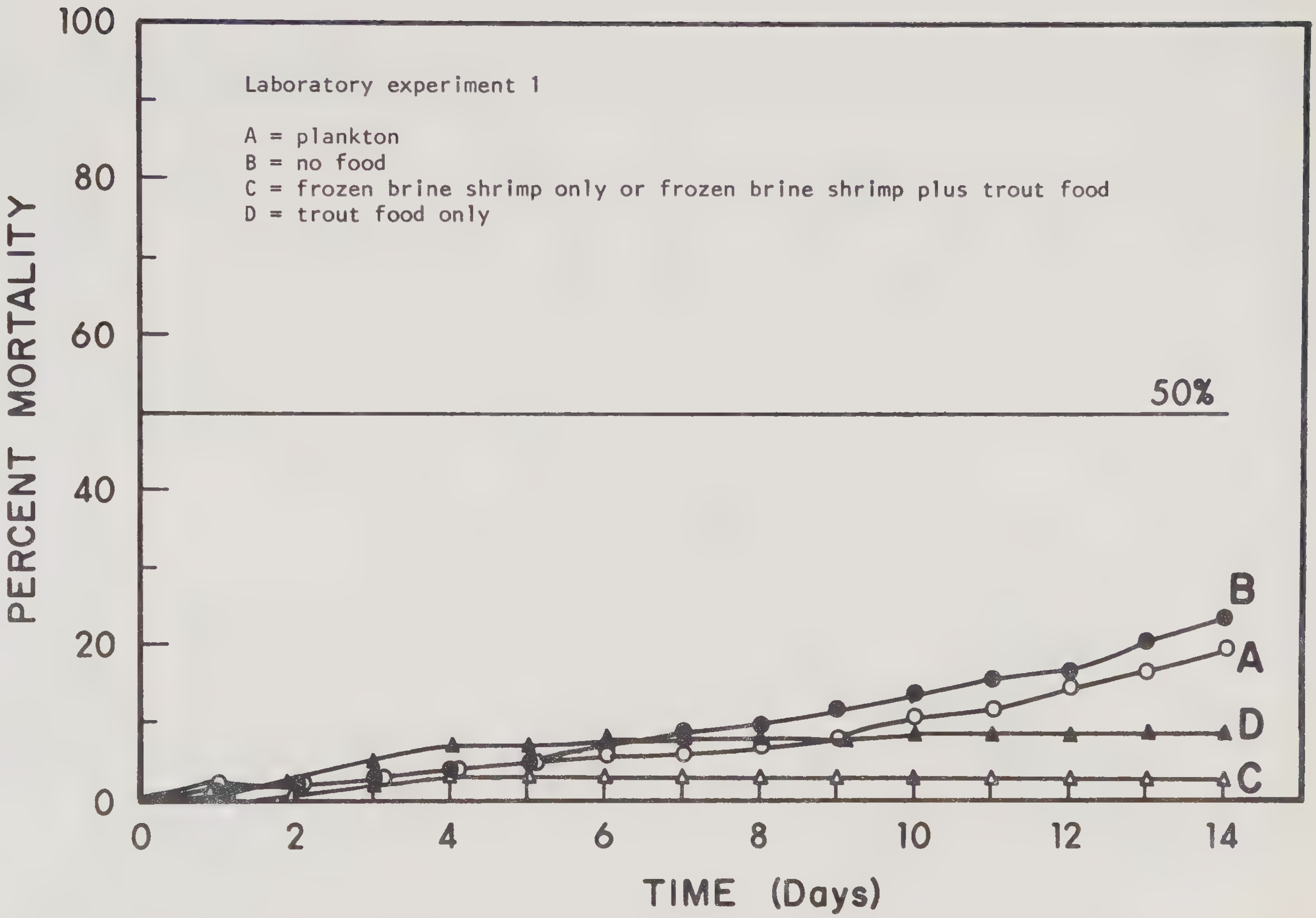


Figure 29. Effect of food type on mortality of acclimated *S. purpureus*.

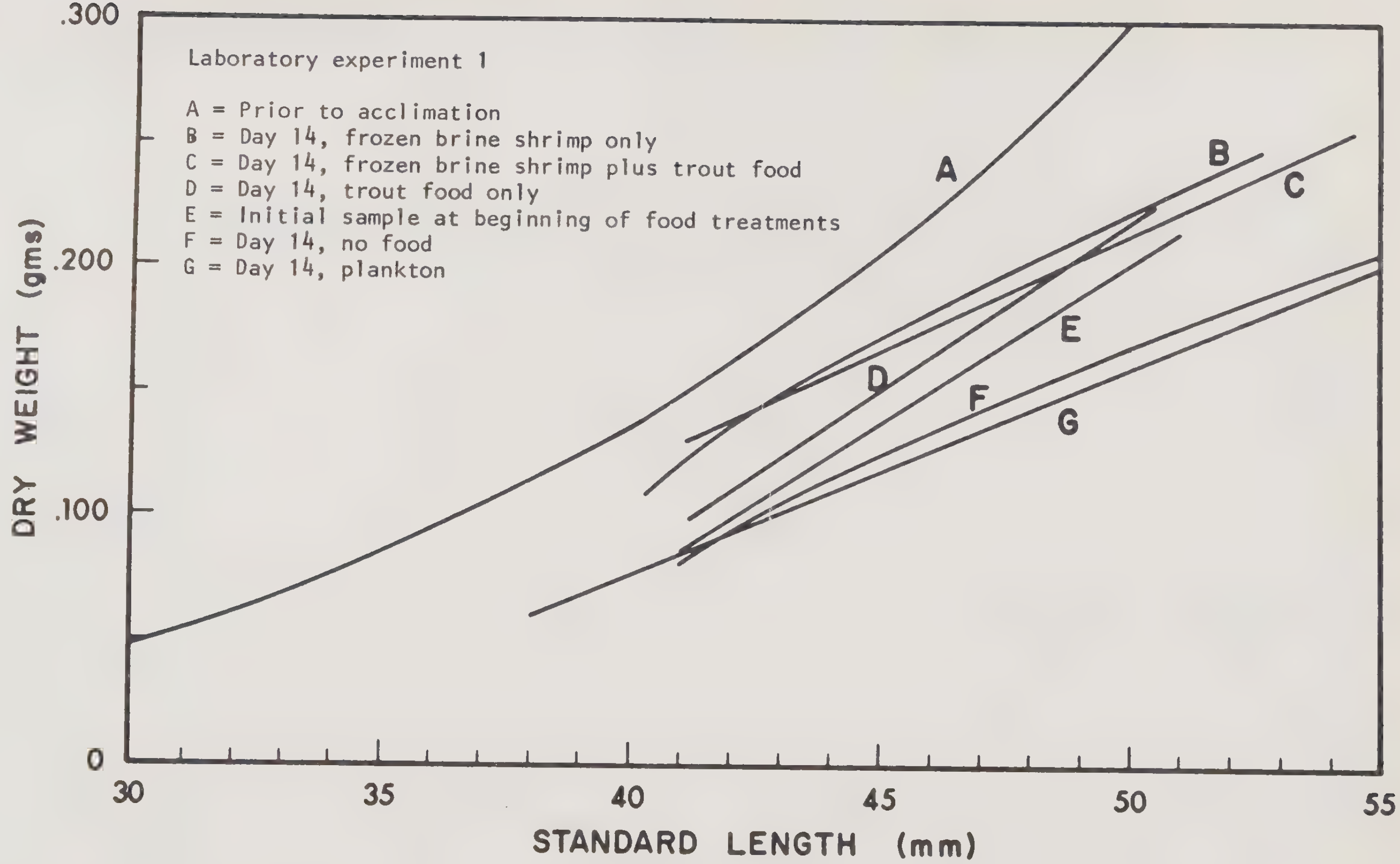


Figure 30. Calculated regression curves of dry weight on standard length of *S. purpureus* before and after different food treatments.

curves F and G) lost weight. Calculated dry weights ($\hat{Y}$) for a mean standard length of 45.0 mm (X) are in Table 18. Fish used in this experiment were given insufficient food during the acclimation period. The experimental initial length-weight regression curve (Figure 30, curve E) does not represent a true estimate for the natural population (Figure 30, curve A). Fish given food treatments resulting in weight gain actually regained weight lost during the acclimation period.

In laboratory experiment 2 (Table 18) the same food treatments were tested on unacclimated fish. These nehu were particularly well-handled night bait which were transferred by swimming into barge wells. Delayed mortality did not begin until about Days 10 and 11 (Figure 31). An interesting result is that those given food (Figure 31, curves A, B, and D) underwent delayed mortality earlier than those given no food (Figure 31, curve C). This would not have occurred if oxygen concentration did not fall below the critical level. In this experiment, however, oxygen stress occurred on Day 8, with oxygen concentration falling below 5.0 ppm. It appears that if low oxygen stresses fish, feeding them results in further stress and ealier delayed mortality. If oxygen is at saturation, no difference in mortality occurs between those fed and those not fed. Starvation mortality in nehu given no food (Figure 31, curve C) began about Days 16 to 18; all fish were dead by Day 20. Length-weight regressions of fish sampled on Day 16, when compared with the regression curve of the initial sample (Figure 32, curve A), showed that fish fed frozen brine shrimp maintained weight (Figure 32, curve B), those fed trout food or trout food plus frozen brine shrimp (Figure 32, curves C and D) lost some weight, and those given no food (Figure 32, curve E) lost most weight. Percentage

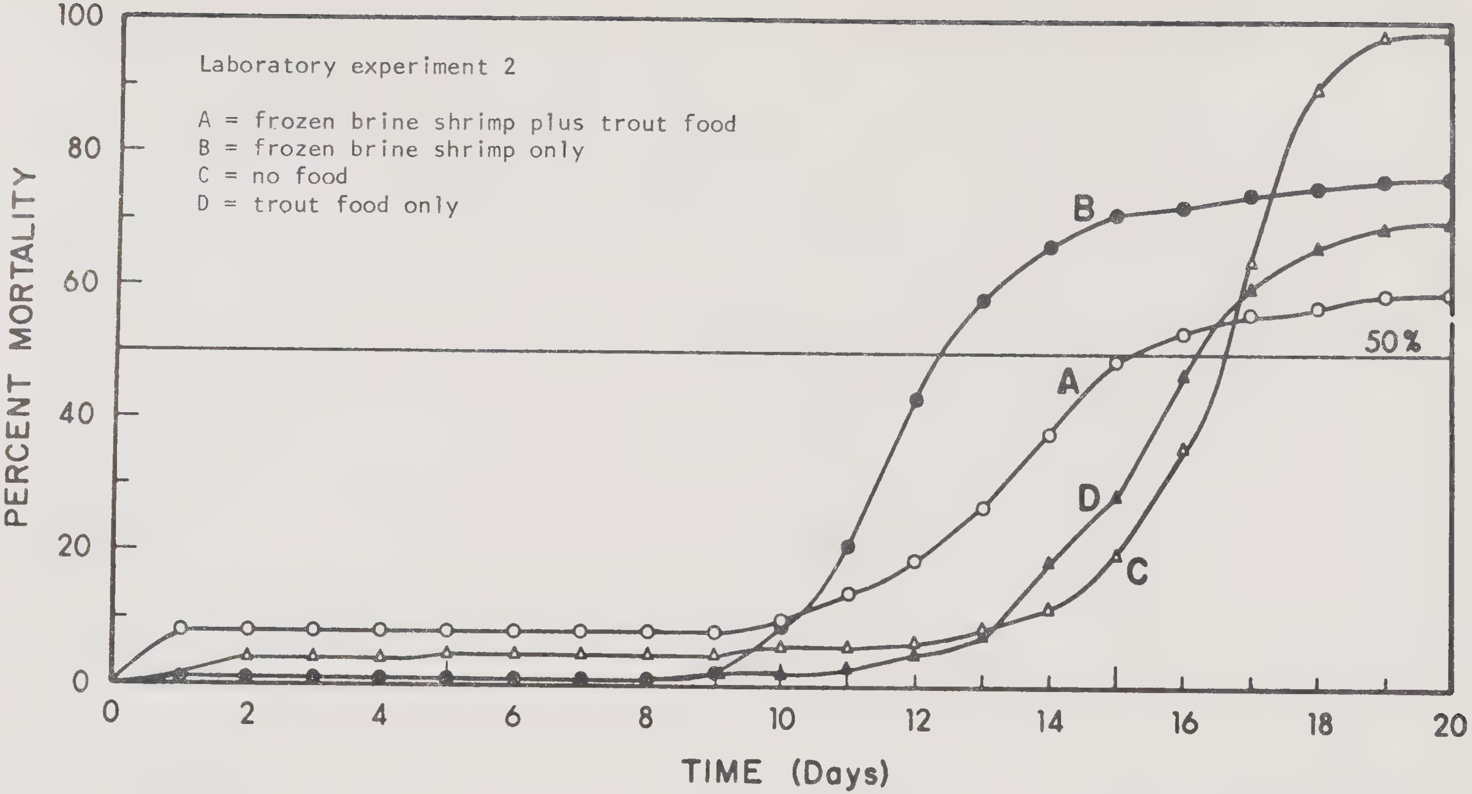


Figure 31. Effect of food type on mortality of unacclimated *S. purpureus*.

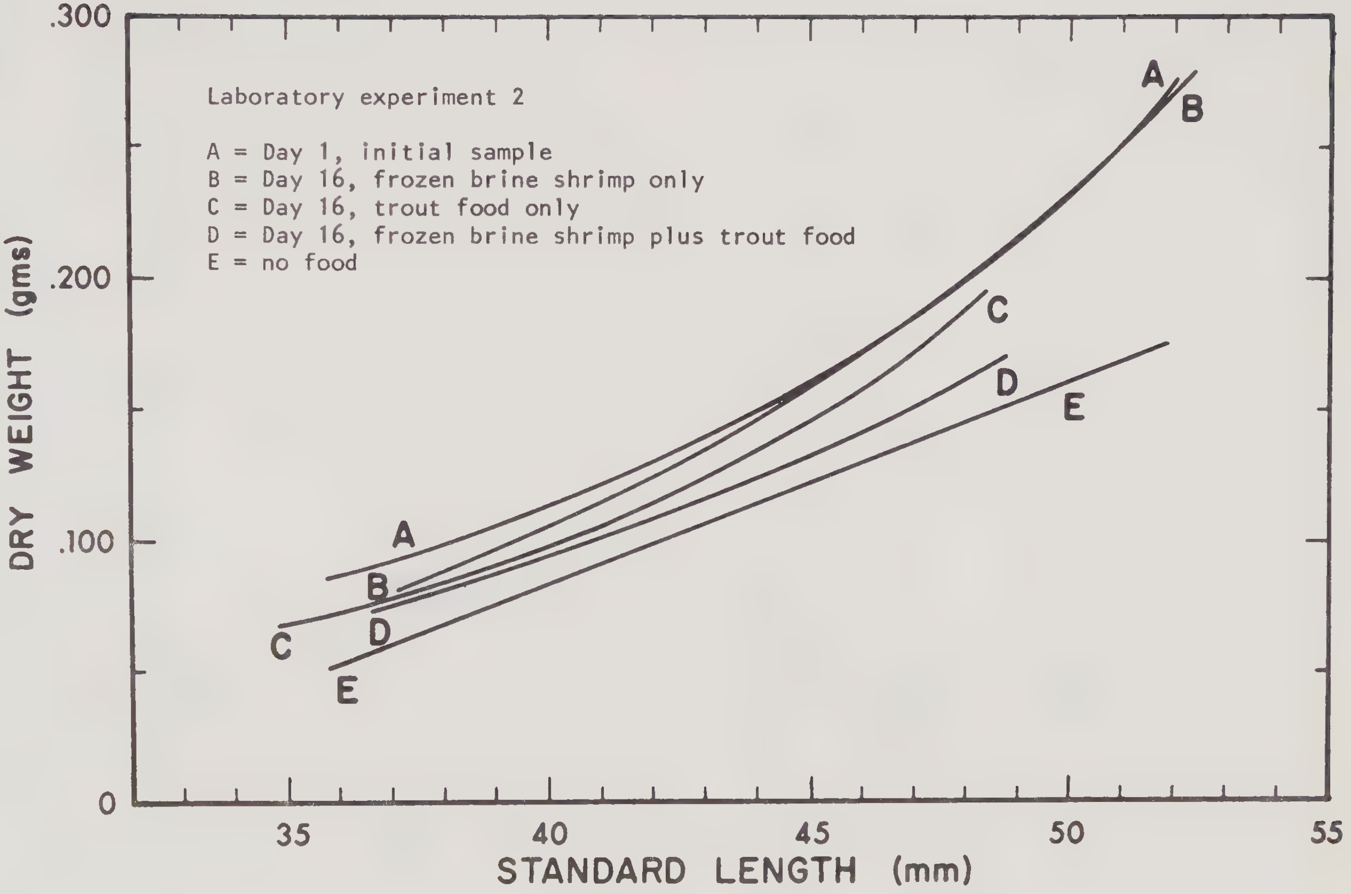


Figure 32. Calculated regression curves of dry weight on standard length of *S. purpureus* before and after different food treatments.

of weight loss or weight gain for different food treatments is compared in Table 18. The only food resulting in no weight loss was frozen brine shrimp.

In barge experiments 7 and 8, all fish were given frozen brine shrimp (wet weight of food approximately 36 percent per gram wet weight of fish; dry weight of food approximately 5 percent per gram wet weight of fish). Figures 33 and 34 and Table 18 show that most fish maintained weight with this food treatment.

Frozen brine shrimp should be washed in fresh water instead of seawater to thaw. This results in brine shrimp sinking more slowly so that fewer are missed by the fish. Excess brine shrimp should be removed from the bottom of the tank after feeding.

If fish are to be held for 10 days or less and used for bait purposes such as on fishing vessels, they should not be fed.

12. Other fishes. Other species of fish are commonly caught with nehu by both day and night capture methods (Table 34). Some are schooling fishes which are not predatory on nehu, such as iao (*Pranesus insularum*) and makiawa (*Etrumeus teres*). Others prey on nehu, such as the carangids (*Caranx mate*, *C. melampygus*, *Gnathanodon speciosus*, and *Scomberoides lysan*). It is best to remove other fish from the bait well, except those which school and are difficult to separate from the nehu. Most large predators should be removed when bait is placed in the tank. Predators stress nehu by attacking them and disrupting normal milling. The final factor analysis shows that the presence of other unpredatory schooling fish may significantly enhance survival by possibly promoting earlier milling.

Adult *Scomberoides lysan* or lae are mid-water or surface carnivores found along coastal areas (Gosline and Brock, 1960). Juveniles approximately 10 to 80 mm in length are found in shallow waters associated with

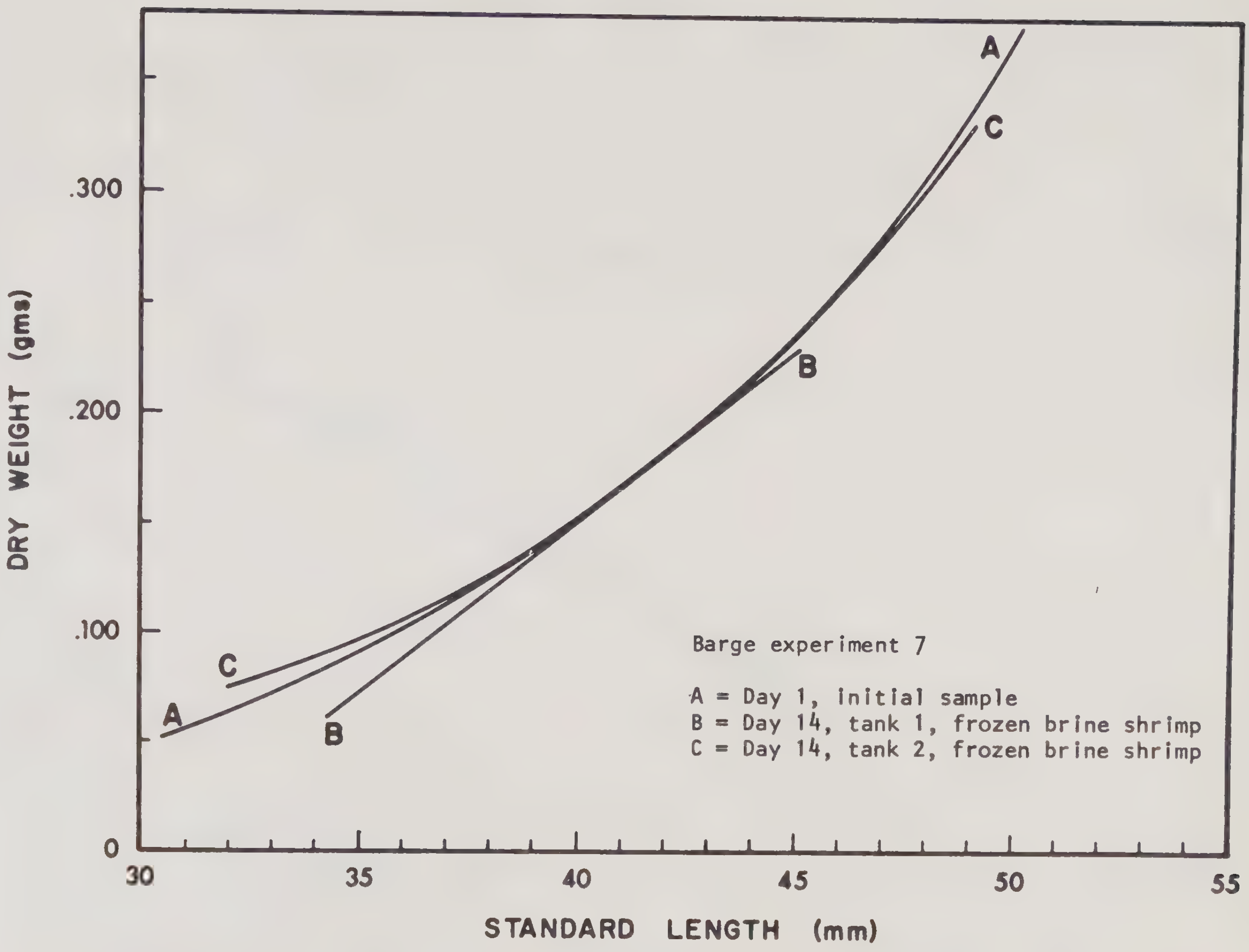


Figure 33. Calculated regression curves of dry weight on standard length of *S. purpureus* before and after fed frozen brine shrimp in both tanks.

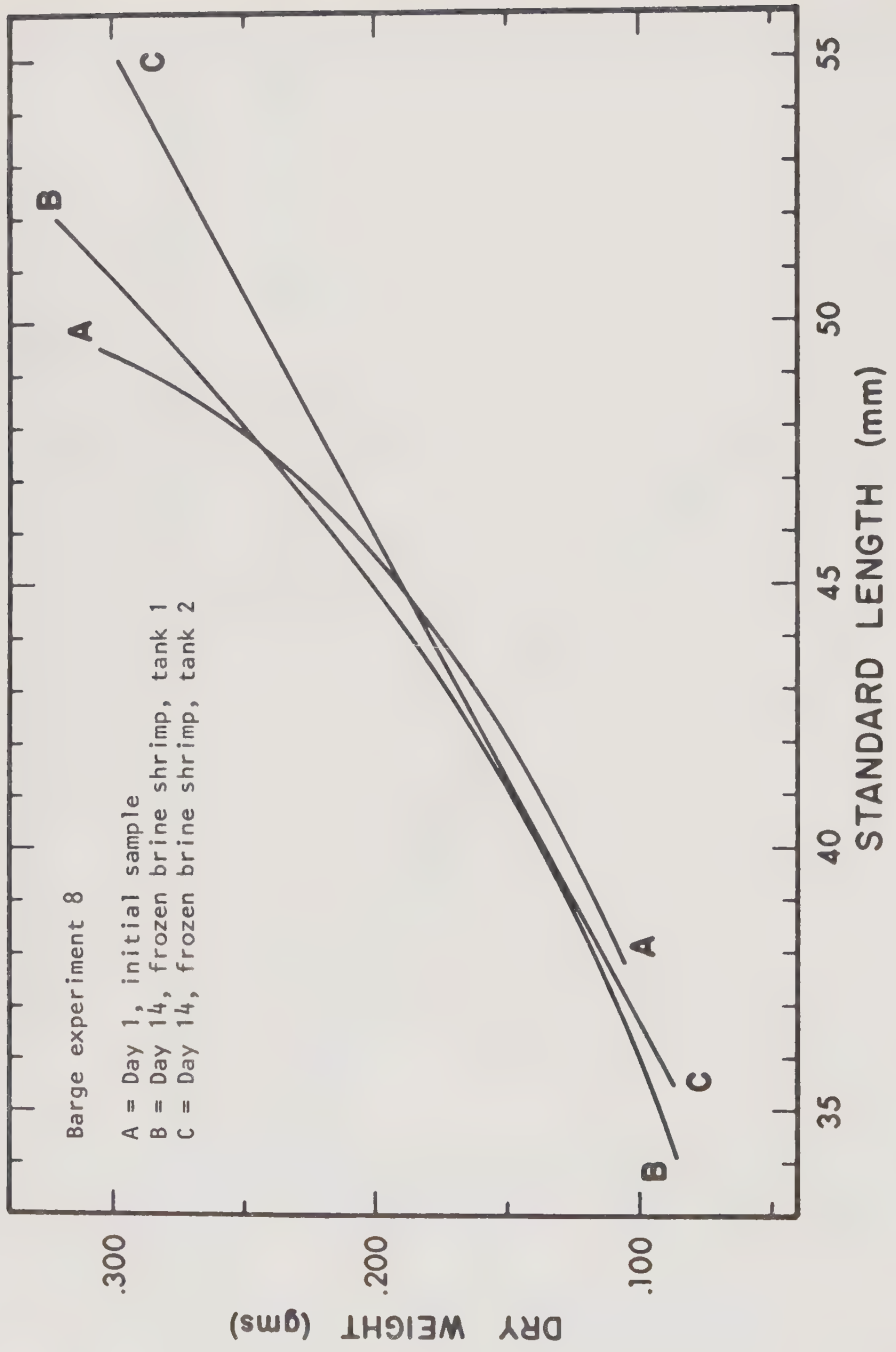


Figure 34. Calculated regression curves of dry weight on standard length of *S. purpureus* before and after fed frozen brine shrimp in both tanks.

schooling fish including nehu. Juvenile lae are frequently captured with nehu from about March to December, but are caught in greatest numbers during July, August, and September, when they become a major stress and mortality factor of nehu in bait wells. During this period, the predominant size is from about 25 to 40 mm. Figure 35 shows the length frequency distribution of a sample of 91 juvenile lae captured with nehu in September. The length of the lae ranged from 23.0 to 63.0 mm; the mean length was 35.2 mm. Lae from about 20 to 50 mm in length feed predominantly on nehu scales. Some scale feeding continues until they reach 140 mm in length (Major, 1973). As they increase in size through the fall and winter months, they begin feeding on juvenile and finally adult nehu. On the other hand, the number of lae captured with nehu rapidly decreases from October through March and bait well mortality caused by lae becomes less.

In a typical attack sequence, lae swim parallel to or above the nehu for about 20 seconds, then dart toward the dorsal area behind the head making contact with the mouth. Simultaneously, the venomous anal spines (Halstead et al., 1972) are lowered although movies made of the attack sequence indicate that lae do not hit or "sting" nehu with the spine, but strike only with the mouth. During the attack, many nehu scales are dislodged and lae eat the free-floating scales. In confinement, lae continually attack and stress nehu until they die. Examinations of dead nehu in tanks with lae reveal that numerous scales in the dorsal area are removed.

Table 19 summarizes laboratory experiments in which lae were present in at least some tanks (180-gal size). Results show that the presence of lae significantly increased mortality of nehu by the end of 13 to 16 days ($P < 0.01$; A vs B and C). Although one to five lae significantly increased mortality ($P < 0.05$), mortality was still less than when six or

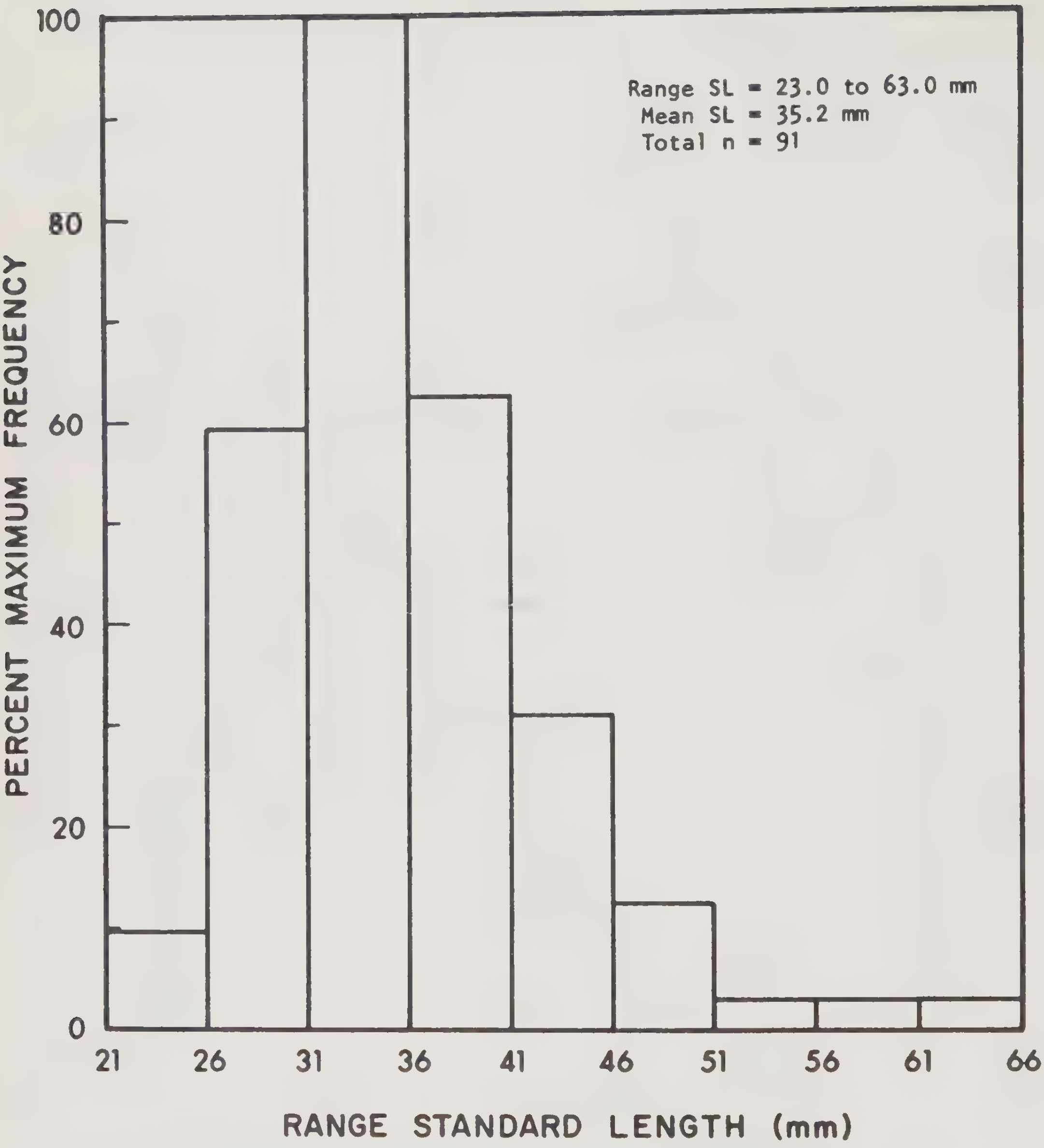


Figure 35. Frequency distribution of standard length of *Scomberoides lysan* captured with *S. purpureus* in September 1970.

more lae were present. More than ten lae in a tank usually effected total mortality of nehu by 13 to 16 days.

The gut contents of lae which are approximately 10 to 50 mm in length were composed mostly of nehu scales and traces of epidermal tissue (C. Moldenhauer, 1967: personal communication). When scales were removed from the nehu and ashed, they contained about 42 to 48 percent organic material. Extracts of homogenized lae intestine were added to samples of nehu scales. The intestinal brie contained enzymes which break down the scales. Observations made so far in addition to other work by Major (1973) on structural changes in teeth with increasing body size strongly support the contention that juvenile *Scomberoides lysan* are predominantly scale-feeders.

Several attempts to eliminate lae from bait wells containing nehu were generally unsuccessful or inefficient. Lowering salinity to a level tolerated by nehu did not kill lae and small traps baited with nehu did not capture them. Fishermen often leave larger fish in bait wells because lae aggregate around them and can then be easily removed with a net. In the laboratory, lae were fed brine shrimp to concentrate them at one end of the tank. When they aggregated where the shrimp were released, they were easily removed with a hand net. Further research on lae would be of interest, not only because of their importance in bait fish mortality, but also because of their unusual scale-feeding behavior during the juvenile stage.

13. Disease and parasites. Although pathogenic bacteria were undoubtedly present in the experiments (Struhsaker et al., 1973), it is unlikely that bacterial disease is a major mortality factor of nehu relative to previously discussed environmental factors. If nehu are kept in

captivity for periods longer than 14 days, however, stress and mortality from bacterial disease may occur, especially in injured fish. Obvious symptoms of common bacterial disease of fish in captivity were not observed in the experiments, but it is possible that if appropriate studies had been made, such diseases may have been revealed.

During warmer months--approximately March through November--nehu are frequently infected by a protozoan, probably a species of *Cryptocaryon* (Nigrelli and Ruggieri, 1966; Wilkie and Gordin, 1969). The infection resembles the common "white spot disease" or "ich" of freshwater fish. Opaque white cysts of diameters varying to a maximum of about 1 mm occur under the gill epithelium. Infections of gills immediately after capture were usually light, 1 to 5 cysts (observed without magnification) in each gill chamber. During the 2 weeks of captivity, the infection increased until a large number of cysts was found in the gills and eventually on the fins and body. The cysts probably seriously impede respiration, causing stress and mortality. Areas infected by protozoan cysts are also possible foci for bacterial infection.

In laboratory experiment 19, it was discovered that reduced salinity (50 percent seawater) effectively eliminated cysts; most after 5 days, all after 10 to 11 days. Figure 36 compares mortality of nehu treated with 100 percent and 50 percent seawater and also shows, for daily samples of 10 fish, percentage of nehu infected by cysts over the experimental period. In the initial sample, all fish were lightly infected with a few cysts. The percentage of nehu infected by at least a few cysts decreased rapidly in 50 percent seawater until most were uninfected by Day 5 and none were infected by Day 11 and throughout the remainder of the experiment (Figure 36, curve A^1). It is probable that cysts develop and fall

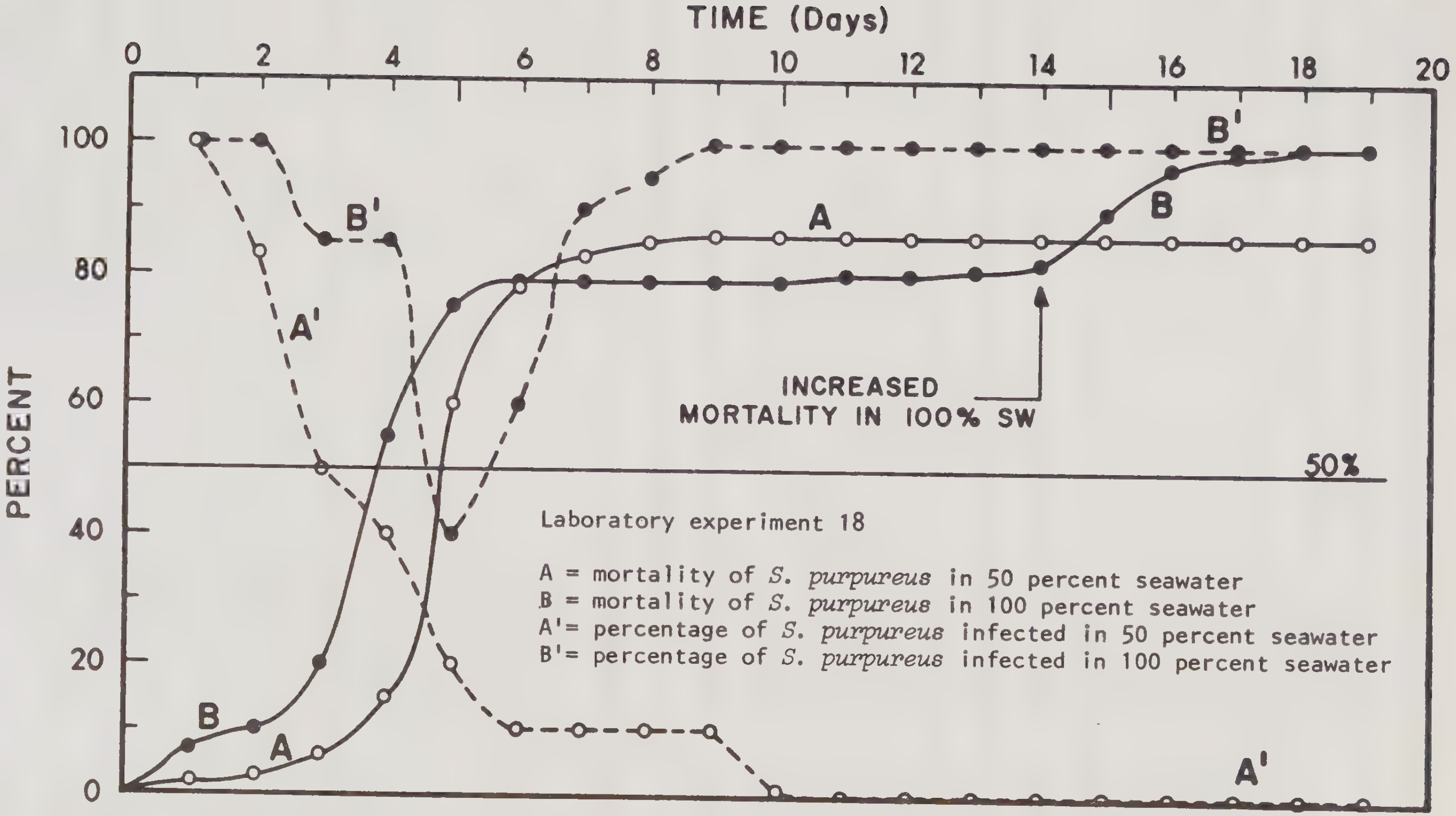


Figure 36. Effect of *Cryptocaryon* sp. protozoan cysts on mortality of *S. purpureus* and the effect of reduced salinity on infection.

off and the emerging free-swimming stages die without reinfecting fish in reduced salinity. No increase in mortality occurred after Day 14 (Figure 36, curve A). In nehu maintained in 100 percent seawater, the infection at first decreased as cysts developed and dropped off. The free-swimming stages survived, however, and began reinfecting fish so that new cysts appeared and increased in number until all fish were heavily infected by Day 9 (Figure 36, curve B^1). An increase in mortality began on about Days 14 to 15, until all fish died by Day 19 (Figure 36, curve B). Infection by this protozoan may contribute to the "weak bait" phenomenon in which nehu die more rapidly during summer months. Continuous exposure to 50 percent seawater in an open system completely eliminates this protozoan disease and may also reduce bacterial infection.

Ectoparasitic isopods of family Cymothoidae are commonly associated with nehu. Although they were observed to injure nehu by biting them, relative mortality from these ectoparasites is probably negligible.

If bait-well conditions are optimal (i.e., if 50 percent seawater is provided, oxygen is at saturation, and density is appropriate), stress and mortality from disease and parasites are probably minimized.

Final Data Analysis of Laboratory and Barge Experiments

A final analysis was performed to determine interrelationships or patterns of environmental variables and their relative effect in producing stress and mortality of *S. purpureus* in captivity. Component factor analysis--analyzing all data variance--was the analytical technique used. Resultant factors are basic dimensions of the vector space of the data. The analysis was accomplished with a 360 IBM Computer using a California Biomedical Program (BMD 03M) for component factor analysis (Dixon, 1970).

A complete treatment of this technique is given by Rummel (1970). Only information pertinent to interpretation of results is given here.

A preliminary analysis of combined data from laboratory and barge experiments disclosed that influence of environmental variables differed between the two locations. Separate analyses were then performed on laboratory and barge data; results are presented separately below. Variables comprehended in analysis of laboratory and barge data are listed in Tables 20 and 21. For laboratory experiments, 34 variables--27 independent and 7 dependent (Table 20)--are included with 184 cases (tanks). For barge experiments, 31 variables--24 independent and 7 dependent (Table 21)--are included with 28 cases (tanks). Some independent variables measured in the laboratory were not measured on the barge. Measurement techniques for independent environmental variables are delineated in the "methods" section. Derivation of dependent variables measuring stress and mortality is described below.

Figure 2 (curves A and D) showed typical mortality curves of *S. purpureus* in captivity. Mortality (Y) is a function of time in days (X) and the relationship is described by the logistic function $\hat{Y}(X) = \frac{Y^{\infty}}{1 + e^{a-rX}}$. Dependent variables used in the factor analysis are parameters of the logistic curve. The day that 50 percent mortality is reached (Y = 50% or Day 50%), the time that delayed or stress mortality begins (X = m or X1-DM), the time that delayed or stress mortality ends (X = n or X2-DM), the total duration of delayed mortality ($X_n - X_m$ or Tot X-DM), the total delayed mortality ($Y_n - Y_m$ or Tot Y-DM), and the time that midpoint of delayed mortality is reached (a/r or A/R) are derived from the logistic function. Initial mortality (Y at X = 1 or %IM) and number surviving (Y at end of experiment or % Survival) are obtained directly from the mortality data.

Stress parameters were derived by putting the logistic functions in the equivalent form of hyperbolic tangent functions (Preisendorfer, 1970; J. Caperon, 1970: personal communication), and then taking the first, second, and third derivatives of these functions. The derivatives are summarized in Table 22. The constants a (Y-intercept) and r (instantaneous rate of increase) were calculated from data using the logarithmic form of the logistic function: $\ln \frac{Y^{\infty} - Y(X)}{Y(X)} = a - rX$. The point at which the second derivative equals zero ($\frac{d^2Y(X)}{dX^2} = 0$) corresponds to the midpoint of delayed mortality (A/R = a/r) in the logistic function; in the hyperbolic tangent function it corresponds to the origin (A = 0). The points where the third derivative equals zero ($\frac{d^3Y(X)}{dX^3} = 0$) correspond to the points of flexure in the logistic curve, or to the beginning and end of delayed mortality, X_n and X_m. X_n and X_m were calculated from the equation for the third derivative using a Basic Program (ZEROES: Hewlett-Packard Program Library) which determines values of X for F(X) = 0, maxima and minima of a defined function over a given X-interval. The value of X at Y = 50%, Total $X(X_n - X_m)$, Y_n, Y_m, and Total $Y(Y_n - Y_m)$ were then calculated for the values of X_n and X_m.

Tables 23 to 27 contain results of component factor analysis of laboratory data. Table 23 includes means, standard deviations, coefficients of variation, and communalities for 34 variables. Coefficients of variation were determined by dividing standard deviation by the mean (Sokal and Rohlf, 1969) and provide a basis for comparing variation within variables of different means. Coefficients of variation for dependent variables (Table 23) indicate less variation in total days of delayed mortality (Tot X-DM) and total delayed mortality (Tot Y-DM) than in level of initial mortality (%IM), time delayed mortality begins (XI-DM), day 50 percent mortality is reached (Day 50%), and number surviving (% Survival). This accords with the observation that, in most experimental environments, duration and extent of delayed stress mortality are relatively invariable; most variation occurs with the onset of delayed mortality and number of fish already dead when delayed mortality begins.

Communalities (Rummel, 1970) represent the proportion of a variable's total variance accounted for by factors and is the sum of squared factor loadings for a variable (Table 25). The sum of communalities divided by the number of variables multiplied by 100 equals the percentage of total variation in all data that is patterned, or the total variance accounted for by factors. It measures order, uniformity, or regularity of data. For the 34 laboratory variables, 82 percent of the total variance is patterned (Table 23).

The correlation matrix for 34 laboratory variables is presented in Table 24. Many significant correlations are not biologically meaningful; some result from experimental and statistical design. Of the biologically interpretable correlations, most variables interrelate in patterns, emerging as significant factors in the rotated factor matrix (Table 25). Others, although not involved in major factors, may significantly correlate with dependent variables. Significant correlations of biological interest which are not included in the discussion of factors are summarized as follows (from Table 24):

1. With current, 50 percent mortality is reached later.
2. With current, delayed mortality is less.
3. With current, number surviving is greater.
4. With increase in hours of recirculated 50 percent seawater, 50 percent mortality occurs later.
5. With addition of protein skimmer, delayed mortality begins later.

6. When fish are fed more, delayed mortality is less and number surviving is greater.

7. With increased exposure to 50 percent seawater, initial mortality is less and delayed mortality begins later.

8. With greater light intensity, 50 percent mortality is reached later, delayed mortality begins later, and a greater percentage survives.

9. With less variation in light, a greater percentage survives.

Other correlations are discussed below in the context of factors.

Orthogonal matrix rotation was employed in this analysis (Rummel, 1970). Factors with eigenvalues equal to or greater than 1.000 were rotated. For laboratory variables, 12 factors were rotated, accounting for 82 percent of the total variance. The orthogonally rotated factor matrix is in Table 25. Some of the 12 factors are not biologically interpretable, relating to variation between cases, i.e., to variation in experimental design from beginning to end of the experiments. Factor 1, for example, relating current, light, total wet weight of fish, and total days in experiment (factor loadings greater than 0.400), is a consequence of modification throughout experiments. In initial experiments, there was no current, less light, fewer fish, and more days. Other factors resulting from variation in experimental or statistical design are Factors 5, 6, 10, 11, and 12.

A summary of biologically significant factors (from Table 25) is given in Table 26. Only variables with factor loadings greater than 0.400 are included, arranged in order from high to low factor loadings. For each factor, the independent and dependent variables are separated. The sign of factor loading gives the direction of the relationship (positive or negative).

In Table 27 the dependent variables are expressed as functions of factors (related independent variables) using the component factor analysis model. Factor 2, the Seasonal Factor, relates handling, baiting, oxygen, month, and mean wet weight. Factor 2 may be interpreted as follows: baiting is a function of month--night baiting is less successful during spring months; bait handling is a function of time of bait capture--night bait is handled less than day bait; mean wet weight of nehu is also a function of time of bait capture--night bait is larger; and finally, a high concentration of oxygen is a function of handling--increased handling requires administering more oxygen. Factor 3, the Temperature Factor, shows temperature as a function of month. Factor 4 is the Other Fish Factor; Factor 7, the Oxygen Factor; Factor 8, the Salinity Factor; and Factor 9, the Predation Factor. Factor 12 is omitted from the following interpretation because it appears to have no biological meaning.

Initial mortality (%IM) shows significant loadings with Factors 2 and 9, the Seasonal and Predation Factors (Table 27). With increased handling, day bait, decreased mean wet weight, high oxygen, and more lae (*Scomberoides lysan*), initial mortality is greater.

The day 50 percent mortality (Day 50%) is reached relates to the Other Fish Factor 4 (Table 27). Other fish in this case are schooling fish, primarily *Pranesus insularum.* Their presence appears to influence survival of *S. purpureus* with 50 percent mortality occurring later and with greater survival. A possible interpretation is that *P. insularum* are often calmer in captivity, mill earlier, and may behaviorally influence nehu survival by promoting earlier milling, thus reducing stress.

The time that delayed mortality begins (XI-DM) relates to Temperature Factor 3 and Predation Factor 9 (Table 27). During summer months when the temperature increases and there is an increase in the number of lae, delayed mortality begins earlier.

The total number of days over which delayed mortality occurs (Tot X-DM) relates to Salinity Factor 8 (Table 27); the higher the salinity, the greater the duration of delayed mortality.

The midpoint of delayed mortality (A/R) relates to Oxygen Factor 7; with critical to lethal levels of oxygen, the midpoint occurs at a higher mortality.

As mentioned above, total mortality (Tot Y-DM) and percentage of fish surviving (% Survival) relate to the Other Fish Factor.

Tables 28 to 32 contain results of component factor analysis of barge data. Tables are comparable with those for laboratory data discussed above. Table 28 includes means, standard deviations, coefficients of variation, and communalities for 31 barge variables. As for laboratory data, coefficients of variation indicate that duration and extent of delayed mortality were relatively invariable among different barge experiments. The total data variance accounted for by the factors (communality) is 92 percent.

The correlation matrix for 31 barge variables is presented in Table 29. Correlations of biological significance not included in the discussions of factors are as follows:

1. In later months--summer and fall--more lae occur.
2. With day bait, a greater duration of delayed mortality occurs.
3. With increase in hours of recirculated 50 percent seawater, a greater percentage of fish survive.
4. With increased exposure to 50 percent seawater, a greater percentage of fish survive.

For barge variables, 9 factors were rotated, accounting for 92 percent of the total variance. The orthogonally rotated factor matrix is in Table 30.

As in the laboratory analysis, some factors are not biologically interpretable, resulting from modification of experimental design. These are Factors 2, 4, 6, 8, and 9.

A summary of biologically significant factors from barge data (Table 30) is in Table 31, arranged in order from high to low factor loadings and with independent and dependent variables separated.

In Table 32, the dependent variables are expressed as functions of factors (related independent environmental variables). Factor 2, the Mixed Factor, associates maximum temperature, mean wet weight, lae, and mean salinity during the experimental period. Mean wet weight is a function of maximum temperature and mean salinity; during summer months, mean wet weight is less and in experiments with reduced salinity, fish do not die as rapidly, resulting in lower mean wet weight. Lae are a function of maximum temperature; during the higher temperatures of summer months more lae occur.

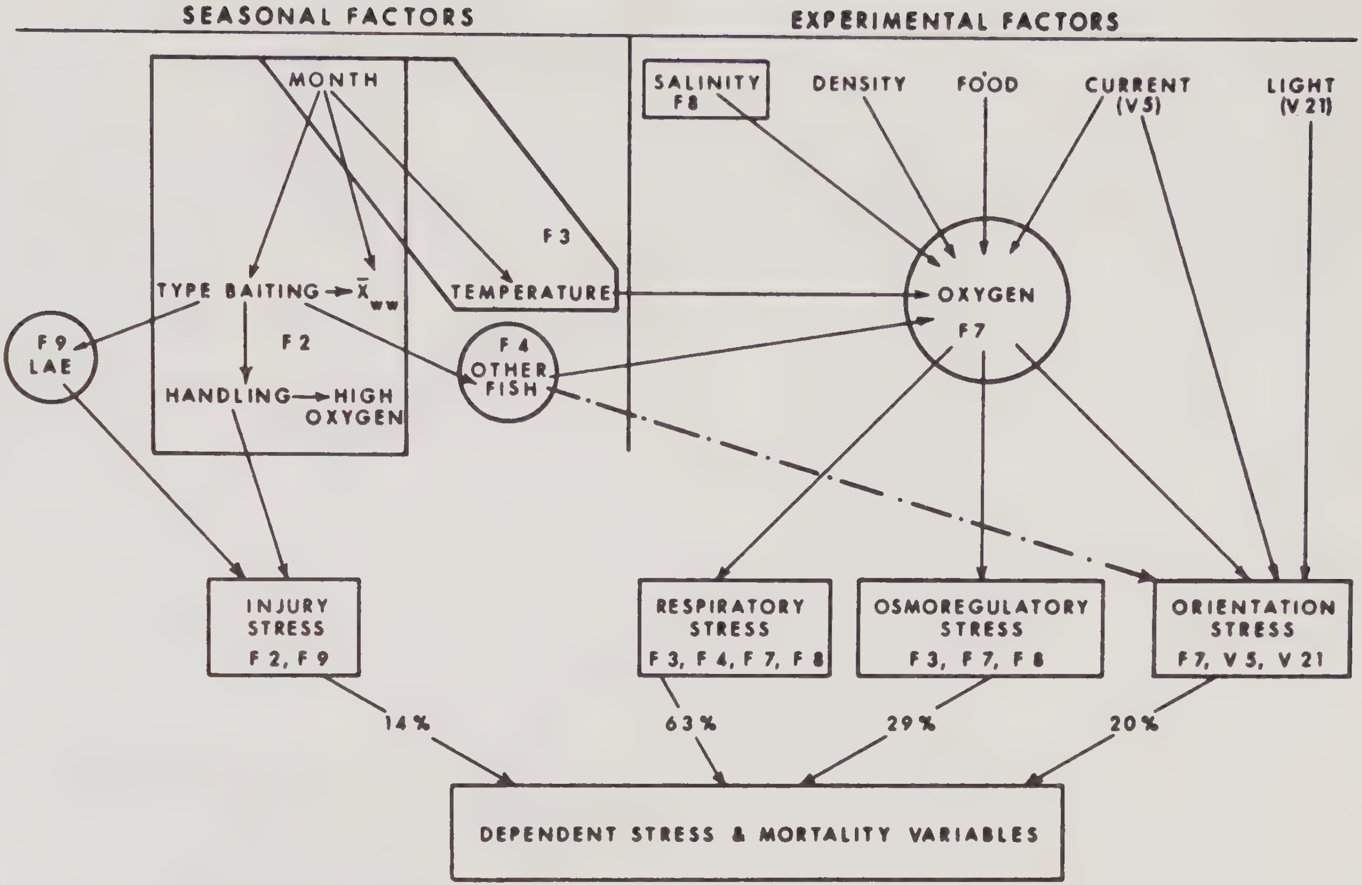
Factor 7 is the Current Factor. Initial mortality shows significant loading with the Current Factor; with current added, initial mortality is less. The remaining dependent variables show significant loadings with the Mixed Factor; the day that 50 percent mortality is reached is later, the time that delayed mortality begins (XI-DM) is later, the total duration of delayed mortality (Tot X-DM) is less, the total mortality (Tot Y-DM) is less, the midpoint of delayed mortality (A/R) is later, and survival is greater with lower maximum temperature, fewer lae, lower mean salinity during experimental period, and greater mean wet weight.

A comparison of factor results for laboratory and barge data is difficult since the number of cases varied greatly between the two locations (184 cases in the laboratory vs 28 cases on the barge). Temperature appears to increase stress and mortality significantly at both locations.

Other variables similarly affected dependent stress variables in the laboratory and on the barge (see correlation matrices, Tables 24 and 29). Differences in degree of stress and mortality between locations are largely a result of different experimental situations, particularly volume of water and circulation rate (both greater in barge wells). Generally, fish survived better in barge wells. The amount of variance accounted for by the rotated factors was greater for barge data (92 percent; Table 28) than laboratory data (82 percent; Table 23).

Further interpretation of factor results could take the form of step-like multiple regressions of significantly related variables within factors. However, since much of the data is non-parametric, further regression analysis appears unjustified.

Figure 37 exhibits a final interpretation of independent variables affecting stress and mortality in terms of causal relationships. Factors and variables are divided into two categories. Seasonal factors ensue from monthly variation in time of bait capture and temperature and experimental factors from experimental design; for example, whether or not current is added or salinity reduced. Factors and variables are then connected by arrows in a hypothetical causal nexus. The strength and direction of the relationships may be determined by reference to the matrix of correlation coefficients in Table 24. Factors and variables are classified into effects on four major types of stress: injury, respiratory, osmoregulatory, and orientation. The relative contribution of each type to total stress and mortality (measured by dependent variables) is shown. Percentage of total variance among dependent mortality variables accounted for by injury is approximately 14 percent; by respiratory stress, 63 percent; by osmoregulatory stress, 29 percent; and by


SEASONAL FACTORS
EXPERIMENTAL FACTORS
MONTH
F 3
TYPE BAITING → $\bar{X}_{ww}$
F 2
HANDLING → HIGH OXYGEN
TEMPERATURE
F 9 LAE
F 4 OTHER FISH
SALINITY F8
DENSITY
FOOD
CURRENT (V5)
LIGHT (V 21)
OXYGEN F7
INJURY STRESS F 2, F 9
RESPIRATORY STRESS F 3, F 4, F 7, F 8
OSMOREGULATORY STRESS F 3, F 7, F 8
ORIENTATION STRESS F7, V 5, V 21
14%
63%
29%
20%
DEPENDENT STRESS & MORTALITY VARIABLES

Factors (related variables) are enclosed.
Percentage of total variance among dependent variables accounted for by factors and variables in shown for four types of stress.
Dashed line indicates an unclear relationship.

Figure 37. Summary diagram showing hypothesized causal relationships between significant independent variables.

orientation stress, 20 percent. A comprehensive partitioning of variance due to factors in the four stress categories is shown in Table 33. A similar figure for barge experiments is omitted because the effect of environmental variables on *S. purpureus* in barge wells is approximately the same as in laboratory tanks.

DISCUSSION

For brevity, discussion of other work relating to individual variables was included under the appropriate variables in the "results and conclusions" section. Interaction of variables was discussed under the "final data analysis" results. Further discussion on the definition and significance of stress follows.

In this paper stress is considered in terms of the effect of environmental stress variables on mortality of *S. purpureus* in captivity. The effect of stress on morphological and functional changes of the endocrine system was not studied, although this would be of interest for future research. The General Adaptation Syndrome (GAS) as defined by Selye (1950) applies in a general way to results of this study in that mortality curves of *S. purpureus* show characteristics in common with the GAS curve. As described by Selye (1950) there is a period of shock with lowered resistance (corresponding to initial mortality in this study); a period of countershock entering into a stage of resistance (early period of no mortality); and finally a stage of exhaustion with decreased resistance (corresponding to the period of a delayed increase in mortality). According to Selye, this syndrome is accompanied in vertebrates by simultaneous changes in the endocrine system which is associated with adaptation to stress conditions. Essentially, the reaction pattern is a failure of part or all of the captive population to adapt to stress. A pattern of negative feedback occurs in which fish initially respond to stress by adapting, but ultimately succumbing. The underlying physiological-hormonal mechanism of the syndrome is not clearly understood in fish.

A definition of stress applicable to this research is that of Brett (1958):

> "...stress is a state produced by an environmental or other factor which extends the adaptive responses of an animal beyond the normal range, or which disturbs the normal functioning to such an extent that, in either case, the chances of survival are significantly reduced. By this definition the magnitude of the stress then becomes possible of quantitative expression by an estimate of the chances of survival (where actual losses can be recorded) or by a measure of reduction in capacity of normal performance."

A systematization of factors into types of stress produced is also given by Brett (1958). To avoid confusion with this analysis in which variables are grouped into factors, it should be made clear that the environmental variables of this study correspond to Brett's factors. The major distinction made by Brett is between discriminate and indiscriminate stress. Discriminate stress is defined as "one which applies at any one time to individuals, singly within a population and not to a group or stock as a whole." Indiscriminate stress is defined as "one which applies to every member and is not discrete in its action." Further distinction is made in four other categories which are defined below with a listing of effective variables from the results given under each category: D = discriminate stress and I = indiscriminate stress.

1. Lethal stress: "The extreme effect of any stress is to destroy the organism."
    a. Handling injury--D
    b. Lethal oxygen level--I
    c. Lethal metabolite levels, i.e., ammonia, carbon dioxide (usually in closed systems)--I
    d. Predation by *Scomberoides lysan*--I

2. Limiting stress: "These are factors which affect the supply of essential metabolites or interfere with the chain of energy release."
    a. Oxygen below saturation, but not at critical level--I
    b. High density (related to oxygen availability)--I
    c. Insufficient food--I
3. Inhibiting stress: "Inhibiting factors reduce the ability of the organism to carry out normal functions and, insofar as this introduces significantly lowered chances of survival, a stress is imposed."
    a. Poor orientation and visual environment (low light intensity, wrong tank color, no current)--I
    b. Parasitism of gills by *Cryptocaryon* sp.--I
    c. Organic particles adhering to gills, e.g., mucus, scales, etc.--I
4. Loading stress: "Any environmental factor which places an undue burden on an organism necessitating the rapid or steady release of energy invokes a stress."
    a. High temperature--I
    b. High salinity, injured integument, shock--I

Under extreme environmental conditions, classification of these variables may change. For example, under poor capture conditions variables listed under limiting, inhibiting, or loading stress may produce lethal stress. The above classification pertains to the capture environment most commonly encountered on fishing vessels.

In most experiments (with the exception of those with optimal environment), approximately 75 percent of the nehu die and 25 percent survive. This survival may correspond to the percentage of older fish in the captive population (mean wet weight approximately 0.7 gm or more), as older fish are less susceptible to stress. Genetic variation is another probable factor of susceptibility to stress.

SUMMARY

With a maximum reduction in handling and the addition of improvements to bait wells, mortality of nehu was reduced from approximately 75 percent to only 10 percent over a period of 14 days. The environmental factors and facility modifications that will give increased survival are summarized below.

1. Time of bait capture. Night bait should be used when possible; fish are usually larger and survive longer. Night capture is most successful in summer and fall, during first quarter-moon phase, and in good weather.

2. Handling. Transfer bait by swimming whenever possible. Avoid bucketing and do not overcrowd buckets.

3. Salinity. Maintain 50 percent seawater (approximately 16.0 to 18.0 ppt) for as long as possible, especially during the first 3 hours after capture. Open system circulation is preferable. In closed systems, recirculate brackish water for no more than 3 hours at a density not to exceed approximately 200 gm per 100 liters (1.6 to 1.8 lb per 100 gal; 8/10 to 9/10 buckets per 100 gal). The pH should not decrease below 7.5.

4. Oxygen. Use supplementary oxygen; concentration should not exceed 10.0 ppm or fall below 5.0 ppm. Ideally, oxygen concentration should be kept at saturation level.

5. Temperature. A range of from 21° to 24°C appears optimal. Higher temperatures should be avoided if possible.

6. Current. Provide horizontal current at approximately 0.10 m/sec (15 to 20 ft/min); not to exceed 0.13 m/sec (25 ft/min). Decrease current speed for smaller or injured fish to minimum required for orientation

on Day 1. Maintain current at least until period of delayed mortality is over.

7. Light. Provide white or green light of at least 1,080 lumens/m (100 footcandles at surface) and of uniform intensity over surface. Higher light intensities may give even better results. Light should also be provided at night.

8. Tank color. Green tanks appear best. Green should approximate Turquoise Green (#25, #75 in *Webster's New International Dictionary of the English Language*, 2nd ed., 1961). Contrasting visual cues on sides of tank may prove helpful. Avoid dark colors, especially black.

9. Tank shape. Circular or rectangular with rounded corners will promote a more uniform, less turbulent current. A central bottom drain for removal of dead should be added.

10. Circulation, flow rate in open system. The maximum flow rate possible without exceeding optimal current speed should be maintained. A turnover rate of at least 50 to 60 percent per hour is optimal; turnover rate should be not less than 40 percent per hour.

11. Recirculation in closed system. Fifty percent seawater should be recirculated for no more than 3 hours at a density of not more than 200 gm per 100 liters (1.6 to 1.8 lb per 100 gal; 8/10 to 9/10 buckets per 100 gal) unless a filtration system is added to remove ammonia and a Trizma buffer is used to sustain pH at about 8.0. Add protein skimmer to remove organic particles, mucus, and scales.

12. pH. Maintain pH at about 8.0 to 8.1. Do not allow pH to fall below 7.6 since a pH of 7.5 is the approximate lethal level. The addition of current may decrease dissolved carbon dioxide and increase pH. Trizma buffer may be used to sustain pH.

13. Density. In an open system, density should not exceed approximately 260 gm per 100 liters (2.2 lb per 100 gal; 1/2 to 1 bucket per 100 gal) unless the flow rate is substantially increased over a minimum turnover rate of 25 percent per hour. In a closed system density should not exceed 200 gm per 100 liters (1.6 to 1.8 lb per 100 gal; 8/10 to 9/10 buckets per 100 gal).

14. Food. Food should not be provided if nehu are to be maintained for short periods. Starvation mortality begins about 10 days after capture. For longer periods in captivity, feed wet weight of brine shrimp (San Francisco frozen brine shrimp) amounting to approximately 36 percent per gram wet weight of nehu, or dry weight of brine shrimp amounting to approximately 3 to 5 percent per gram wet weight of nehu. Begin feeding on Day 3 and feed 3 times daily or more.

15. Other fishes. Remove large predators captured with nehu. Remove lae as described in the "results" section. Leave other schooling fish in the bait wells, as they appear to increase the survival of nehu.

16. Disease. Fifty percent seawater (16.0 to 18.0 ppt) effectively eliminates *Cryptocaryon* sp. cysts from gills of nehu in about one week. To reduce possible bacterial stress, all dead nehu, debris, and excess food should be removed twice a day.

17. Bait well design. The above improvements have been incorporated into a new bait well design (Baldwin, 1973). A brochure for fishermen outlining procedures and improvements was prepared by Baldwin et al. (1972).

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APPENDIX

CAPTIONS FOR TEXT TABLES

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2	Night baiting, factor analysis; factor matrix
3	Analysis of variance between buckets of nehu captured at different seasons
4	Analysis of variance between buckets of nehu captured at different moon phases
5	Summary of standard length, wet weight, dry weight, and regressions of wet and dry weight on standard length
6	Differential mortality of size
7	Summary of initial mortality in laboratory tanks with 50 percent as opposed to 100 percent seawater
8	Summary of selected experiments with reduced salinity; open system
9	Recovery of body water in nehu by Day 14; different oxygen levels
10	Approximate rates of oxygen consumption of *Stolephorus purpureus* under different experimental conditions
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Table

20 List of variables measured in laboratory experiments included in factor analysis

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22 Derivation of first, second and third derivatives of logistic equation in form of hyperbolic tangent function

23 Factor analysis, laboratory experiments; means, standard deviations, coefficients of variation and communalities

24 Factor analysis, laboratory experiments; correlation matrix

25 Factor analysis, laboratory experiments; factor matrix

26 Factor analysis, laboratory experiments; summary of factors

27 Factor analysis, laboratory experiments; dependent variables as functions of factors

28 Factor analysis, barge experiments; means, standard deviations, coefficients of variation and communalities

29 Factor analysis, barge experiments; correlation matrix

30 Factor analysis, barge experiments; factor matrix

31 Factor analysis, barge experiments; summary of factors

32 Factor analysis, barge experiments; dependent variables as functions of factors

33 Percentage of variances of dependent variables accounted for by factors affecting four categories of stress

34 List of fish species captured during night and day baiting operations

35 Oxygen line pressure necessary to provide sufficient oxygen for nehu consuming from 100 - 170 cc oxygen/hr at different concentrations in buckets

36 Flow rate necessary to provide 1,270 cc oxygen/hr for one bucket of nehu, no supplemental oxygen

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MFR PAPER 1169

Exploratory Shrimp Trawling in the Hawaiian Islands

PAUL STRUHSAKER and HOWARD O. YOSHIDA

ABSTRACT—The results of exploratory shrimp trawling in the Hawaiian Islands during six cruises of the RV Townsend Cromwell *are given. One species of shrimp,* Penaeus marginatus, *was found in quantities thought sufficient to sustain a small trawl fishery. Average catches in the four most productive areas ranged from 4.7 to 31.0 pounds (2.1 to 14.1 kg) per hour (heads-on weight) with a single 41-foot (12.5-m) shrimp trawl. Evidence is presented that individual shrimp move offshore into depths of 100-125 fathoms (185-230 m) during daytime, with most individuals returning to shallower depths of 35-100 fathoms (65-185 m) during night. Optimum trawling speed was between 2.3 and 3.0 knots with best catches being made at 2.5-2.8 knots. The size of the shrimp at most stations ranged from 16 to 19 individuals per pound (heads-on). In any given depth range the females tend to be larger than males. In depths greater than 100 fathoms (185 m) the males are 3-4 times more numerous than females. Small amounts of shrimps of the genera* Heterocarpus, Aristeus, Pandalus, *and* Pleisioneka *were taken in depths of 150-385 fathoms (275-705 m), but never in quantities sufficient to justify the sorting effort required. Catches of white crabs ranged up to 30 pounds (13.6 kg) per tow, while incidental catches of slipper lobsters, spiny lobsters, and kona crabs were also made.*

Figure 1.—A portion of a catch of *Penaeus marginatus* trawled in the Hawaiian Islands.

During the 1902 expedition of the U.S. Fish Commission's steamer *Albatross* to the Hawaiian Islands, large specimens of the penaeid shrimp, *Penaeus marginatus* Randall (Fig. 1), were taken with beam trawls in Pailolo Channel at depths of 122-141 fathoms (220-255 m) (Rathbun, 1906). Because contemporary charts indicated that Pailolo Channel and other areas of the Hawaiian Islands offered moderate amounts of grounds that might be trawlable in depths presumably inhabited by adult *P. marginatus*, the National Marine Fisheries Service (NMFS), in cooperation with the Hawaii Institute of Marine Biology, conducted four exploratory trawling cruises with the RV *Townsend Cromwell* during 1967 and 1968 to assess the demersal shrimp and fish resources of the main group of the Hawaiian Islands (Fig. 2). Yoshida (1972) reported on the shrimp catches for the first three cruises, while Struhsaker (1973) discussed the ichthyological results. The results of these four cruises and subsequent trawl surveys during 1971-72 are summarized here. We conclude from these investigations that *P. marginatus* occurs in sufficient quantities to support a small commercial trawl fishery.

GEAR AND METHODS

Most of the trawling effort during the first four cruises was conducted with 41-foot (12.5-m) headrope 4-seam flat shrimp trawls such as described by Bullis (1951) and Schaefers and Johnson (1957). Similarly constructed trawls with headrope lengths of 27 feet (8.3 m) and 71 feet (21.5 m) were also utilized during the first cruise, as was a 71-foot headrope fish trawl (Greenwood, 1958).

Trawling surveys conducted during 1971-72 utilized, almost exclusively, 41-foot headrope 4-seam flat and semiballoon shrimp trawls similar to those described by Greenwood (1959), with mud rollers mounted about every three feet (1 m) on the foot rope. A 60-foot (18.3-m) headrope semiballoon

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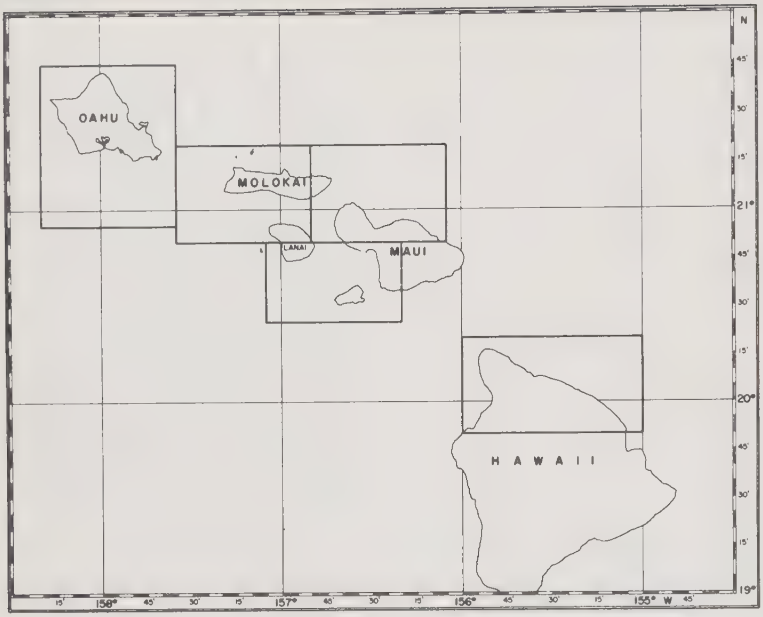

Figure 2.—General areas where trawl surveys were conducted in the main group of the Hawaiian Islands.

shrimp trawl with no mud rollers was briefly tested during fall 1972.

The shrimp trawls were all constructed of 1.5-inch (38-mm) stretched mesh nylon webbing throughout the body and cod end. The foot ropes were weighted with 0.25-inch (6-mm) loop-chain attached at 1-foot (0.3-m) intervals. Tickler chains of 0.25-inch stock were used on all shrimp trawls.

The 41-foot trawls were fished on a single wire with a 15-fathom (27-m) bridle. Although conventional Gulf of Mexico type wooden doors (Bullis, 1951) were tried initially, modified aluminum V-doors as described by Barraclough and Johnson (1960) were used at most of the stations. The aluminum doors were superior to the wooden doors, especially in the deeper sets. The 60-foot trawl was fished with two warps and spread with 7-foot (2.1-m) steel Chinese V-doors.

During the first four cruises, 225 shrimp trawl stations were conducted in the 35-385 fathom (66-705 m) depth range. At 161 stations the 41-foot flat trawl was used and fished correctly with little or no damage. Additional shrimp trawling stations were effected during spring 1971 (23 stations) and fall 1972 (29 stations). Single trawls were fished at all stations and towing times ranged from about 0.5 to 4.0 hours, with most hauls ranging from 1 to 2 hours in duration.

One advantage of deep-water trawling in areas similar to the Hawaiian Islands is that the nearness of the land masses provides fixed geographic reference points for accurate positioning of vessels not equipped with precision navigational systems. Position data are probably accurate to less than 0.1 mile. We considered that a tow began at "dog-off" and ended at the beginning of "haul-back." Although the actual times that the trawl began and ended fishing were not accurately known, it was assumed that the time lags at the start of both operations approximately canceled one another. This assumption is probably valid for shallow waters, but greater variance must be assumed with increased fishing depths. Stations where the gear fished satisfactorily and suffered no damage, or damage so slight that it was considered that the sampling efficiency of the trawl was not affected, were considered to be "quantitative." These stations were used in the calculation of catch rates of shrimp to determine the effects of trawling speed, depth of water, and time of day. For the determination of catch rates per unit area, it was assumed that the 41-foot trawls had an effective sampling width of 23 feet (7 m).

During the first cruise, emphasis was placed on becoming familiar with bottom trawling techniques and gaining an introductory knowledge of the bottom resources in depths greater than 100 fathoms (185 m). Two subsequent cruises during spring 1968 emphasized the exploration of additional areas that might have harvestable populations of *P. marginatus*. During the fourth cruise (fall 1968), four areas where *P. marginatus* was found to be most abundant during the previous cruises were extensively surveyed to determine the availability of the species in relation to the factors of depth and time of day.

Although some gear damage was experienced during all cruises, once the characteristics of the various areas were learned tear-ups were greatly reduced. During the last cruise when 119 trawling stations were effected, only four tows were unsuccessful: one was a water-haul; very light trawl damage was experienced at two stations; and heavy damage was experienced at one station. The last station was an attempt to sample a broken-bottom area in shallow water.

RESULTS

Trawling Areas and Shrimp Catches

The four areas where the best catches of *P. marginatus* were made are discussed first. The catch rates for these areas are summarized in Table 1. Most of the data are for fall 1968 when the greatest number of quantitative stations were made. The results of fishing during spring 1971 and fall 1972 in the Pailolo-Molokai area are also given. All catch weights (heads-on) are for single 41-foot shrimp trawls except for the 1972 samples when a 60-foot shrimp trawl was used. Areas where only small catches of *P. marginatus* were made, or where other species of shrimp were found are also discussed.

Northwest Molokai

Although the northeastern coast of the island of Molokai presents one of the world's most dramatic sea scarps, which continues in places to great depths, the undersea portion of the

Table 1.—Catches of *Penaeus marginatus* with a 41-foot shrimp trawl in four areas of the Hawaiian Islands (heads-on weights).

Area and time	Year	No. of stations	Range of catch per station lb	Range of catch per station kg	Range of catch per hour lb	Range of catch per hour kg	Average catch per station lb	Average catch per station kg	Average catch per hour lb	Average catch per hour kg
Northwest Molokai	1968									
Night		9	5-16	2.3- 7.3	2.3- 7.6	1.0- 3.5	10.9	5.0	4.7	2.1
Penguin Bank	1968									
Night		16	11-33	5.0-15.0	5.5-19.4	2.5- 8.8	20.4	9.3	10.8	4.9
Pailolo Channel-Maui	1968									
Night		10	4-35	1.8-15.9	2.4-17.5	1.1- 8.0	15.3	7.0	7.6	3.5
Day		6	2-29	0.9-13.2	1.1-13.2	0.5- 6.0	18.8	8.5	9.5	4.3
Pailolo Channel-Molokai	1968									
Night		7	6-53	2.7-24.1	2.9-23.0	1.3-10.5	23.4	10.6	11.3	5.1
Day		7	33-105	15.0-47.7	17.4-47.7	7.9-21.7	59.1	26.9	31.0	14.1
	1971									
Night		4	23-58	10.5-26.4	11.6-27.2	5.3-12.4	34.8	15.8	18.1	8.2
Day		6	42-75	19.1-34.1	20.8-37.5	9.5-17.0	59.7	27.1	29.8	13.5
Day	1972	10	40-75	18.2-34.1	20.0-37.5	9.1-17.0	55.1	25.0	27.5	12.5

northwest coast is a continuation of the low, gently sloping west Molokai Dome until the shelf break is encountered at about 95 fathoms (175 m). West of long. 157°05′W, trawlable bottom extends for about 10 nautical miles (18 km) in depths of 55-95 fathoms (100-175 m) (Fig. 3). The bottom type is muddy sand with moderate amounts of sponge. Although the surveys were restricted to an area estimated to be 5.5 square nautical miles (18.7 km²), quite possibly this ground could be extended to a greater depth and farther westward.

Of the four most productive areas, northwest Molokai was the shallowest and produced the smallest catches. During fall 1968 the depths sampled ranged from about 65 to 70 fathoms (120 to 130 m). *P. marginatus* was only taken during night tows with catches ranging from 5 to 16 pounds (2.3 to 7.3 kg) per station (Table 1).

Penguin Bank

An 8-mile (14.8-km) long trawlable area of about 3.0 square miles (10.3 km²), centered on the 100-fathom (185 m) depth curve between long. 157°22′W and 157°30′W, was located on the north edge of Penguin Bank west of Molokai (Fig. 3). The bottom type is coralline sand and rubble with moderate amounts of sponge and algae. A few subsequent stations during 1971 demonstrated that the depth limits and east-west boundaries of the area sampled may be extended somewhat.

This area was the second shallowest, with most tows being made in the 100-fathom (185-m) depth range. Again, almost all catches of *P. marginatus* were made at night, although frequently a few shrimps were taken during day stations (<1 pound per station). The night catches ranged from 11 to 33 pounds (5-15 kg) per tow (Table 1).

Pailolo Channel

Pailolo Channel, between the islands of Maui and Molokai (Fig. 4), may be likened to a dead-end canyon sloping gently to the northeast with a level floor of muddy sand at depths of 120-130 fathoms (220-247 m). Although the entire channel in these depths is generally trawlable, the best shrimp catches were made in depths of 110-120 fathoms (200-220 m) on the southeast edge of the channel near Maui and on the northwestern edge near Molokai. The "Pailolo Channel-Maui" ground extends from about lat. 21°03.2′N, long. 156°41′W to lat. 20°58.2°N, long. 156°46.3′W, a distance of about 7 miles (13 km), with an area of about 3 square miles (10.2 km²). The "Pailolo Channel-Molokai" ground extends from about lat. 21°05.5′N, long. 156°42.5′W to lat. 21°01.5′N, long. 156°50′W, a distance of about 8 miles (14.8 km), with an area of about 4 square miles (13.7 km²).

The better catches of *P. marginatus* were made in the 110-120 fathom (200-220 m) depth range in Pailolo Channel during both day and night hours. Catches on the Maui side of the channel ranged from 4 to 35 pounds (1.8-15.9 kg) during night stations and 2 to 29 pounds (0.9-13.2 kg) during day stations. However, the day stations yielded a higher average catch than the night stations (Table 1).

Stations made during 1968 on the Molokai side of Pailolo Channel produced the best catches of *P. marginatus*. They ranged from 6 to 53 pounds (2.7-24.1 kg) per tow at night and 33 to 105 pounds (15-47.7 kg) per tow during daylight hours (Table 1). During spring 1971, when a 41-foot

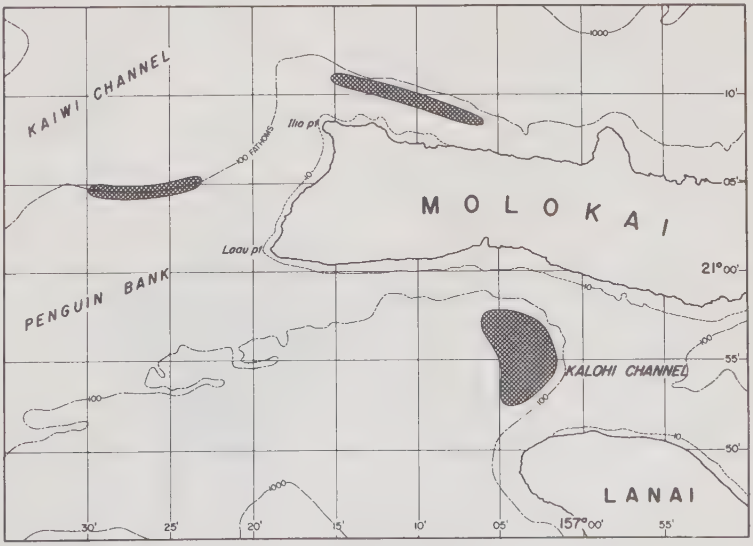

Figure 3.—Trawlable areas (hatched) in the vicinity of west Molokai.

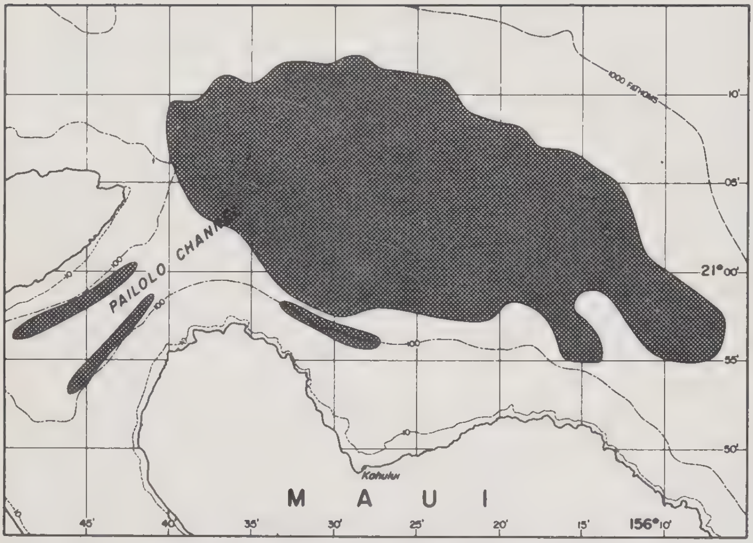

Figure 4.—Trawlable areas in Pailolo Channel and north of Maui.

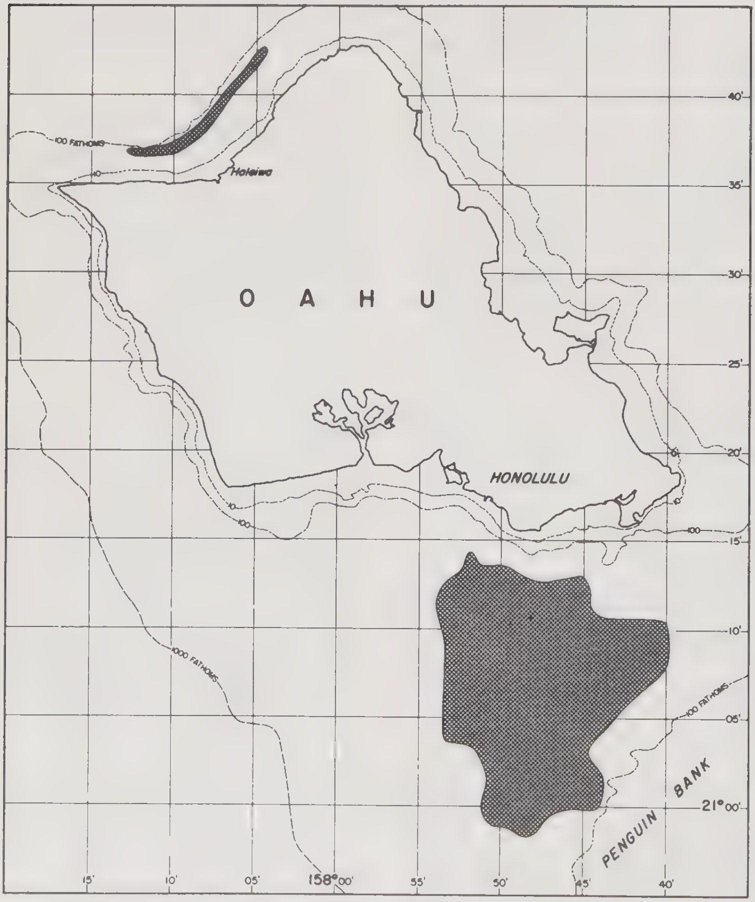

Figure 5.—Trawlable areas near Oahu.

semiballoon trawl with mud rollers was utilized, catches were similar. Night tows at that time produced catches of 23-58 pounds (10.5-26.4 kg), while day tows ranged from 42 to 75 pounds (19.1-34.1 kg). Finally, during fall 1972, 10 daylight stations with a 60-foot shrimp trawl without mud rollers produced catches of 40-75 pounds (18.2-34.1 kg). These stations with the larger trawl produced smaller average catches than the previous sampling with 41-foot trawls, probably because optimum trawling techniques with the gear were not yet fully developed during this series of stations.

Areas where only small catches of *P. marginatus* and other species of shrimp were taken are discussed below.

Haleiwa

Good trawlable bottom was located off the north coast of Oahu in the 55-65 fathom (95-115 m) depth range (Fig. 5) during the cruises conducted in 1968. Smooth sandy bottom extends from due north of Haleiwa northeast to the latitude of Kahuku Point and no trawling difficulties were experienced. A secondary area extends from off Haleiwa westward 5 miles to about long. 158°12′W consisting primarily of smooth sand bottom with some coral and rock outcrops. Trawling was generally successful, but occasional gear damage caused this latter area to be classified as "marginal." Live sponges often made up a large portion of the catches in both subareas.

A few subsequent stations during 1972 demonstrated that trawlable bottom extends out to depths of 120 fathoms (220 m) between Haleiwa and Waimea Bay.

Although substantial sampling was conducted at depths of 55-65 fathoms (95-115 m), catches of *P. marginatus* were made only at night and were considered to be spotty. Catches during fall 1968 ranged from 0.2 to 3.0 pounds (0.1-1.4 kg) per tow. Six night-trawl stations further offshore in depths of 80-120 fathoms (145-220 m) during 1972 produced catches ranging from 3 to 11.5 pounds (1.4-5.2 kg) per hour. Although further delineation of trawlable grounds in the deeper water portions off north Oahu is desirable, it would seem that moderately good catches could be made on a sustained basis.

Maui

An extensive area of trawlable grounds was located off the north coast of Maui (Fig. 4), but most of it lies in depths of 175-350 fathoms (325-650 m), below the depth range inhabited by *P. marginatus*. During the 1967-68 cruises, the bottom off north Maui in depths less than about 150 fathoms (275 m) was classified as only marginally trawlable. Several stations were effected in depths of 35-40 fathoms (65-75 m), resulting in a best catch of 4 pounds (1.8 kg) of *P. marginatus* for a 1-hour tow. Two additional stations made during 1971 indicated that trawlable grounds are present in the 95-120 fathom (175-220 m) depth range. This latter area extends from north of Kahului Harbor west-northwest for about 7 miles (13 km) along the 100-fathom (185 m) curve (Fig. 4). The stations were made during daylight hours and the best catch was 9.2 pounds (4.2 kg) for a 2-hour tow. Further explorations in this area seem warranted.

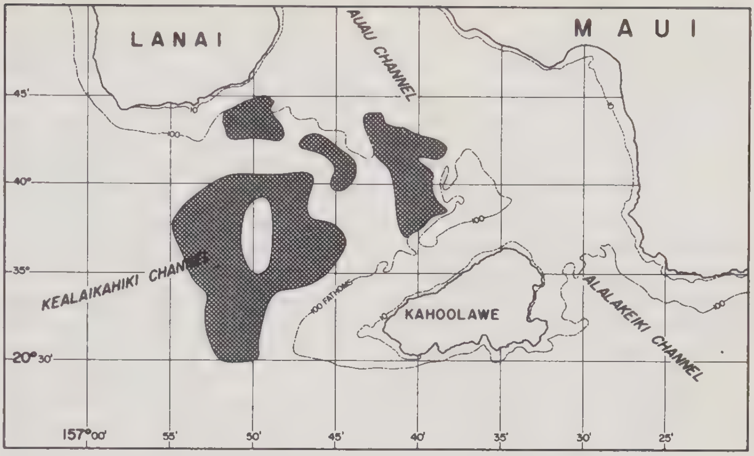

Figure 6.—Trawlable areas between the islands of Lanai and Kahoolawe.

Kealaikahiki Channel

Good trawlable grounds were located in Kealaikahiki Channel between the islands of Lanai and Kahoolawe (Fig. 6). Approximately half of the area bounded by the 100-fathom (185 m) curve on the north, east, and south, and 250 fathoms (455 m) to the westward consists of smooth mud and sandy mud bottom. Small amounts of *P. marginatus* were taken off southeastern Lanai. All stations were made during the first cruise, and the sampling gear used here was less efficient than that used on later cruises. Best catches were made with a 27-foot shrimp trawl which resulted in 27 shrimps taken in a 60-fathom (108 m) night tow and 28 taken in a 124-fathom (226-m) day drag (both tows of 1-hour duration).

Hamakua Coast

The Hamakua Coast of northeast Hawaii (Fig. 7), between Waipio Valley and Hilo Bay, offers good trawling grounds in depths inhabited by *P. marginatus*. However, sugarcane plantations along the coast have been dumping cane trash directly into the ocean for many years. Large quantities of trash taken in the trawls (up to 3,000 pounds) so hampered the operations that extensive trawling was not undertaken. Our limited sampling was insufficient to determine what effect, if any, the cane debris has on the bathyal environment and associated animal communities. There is little doubt, however, that this area is an excellent example of a deepsea environment extensively altered by

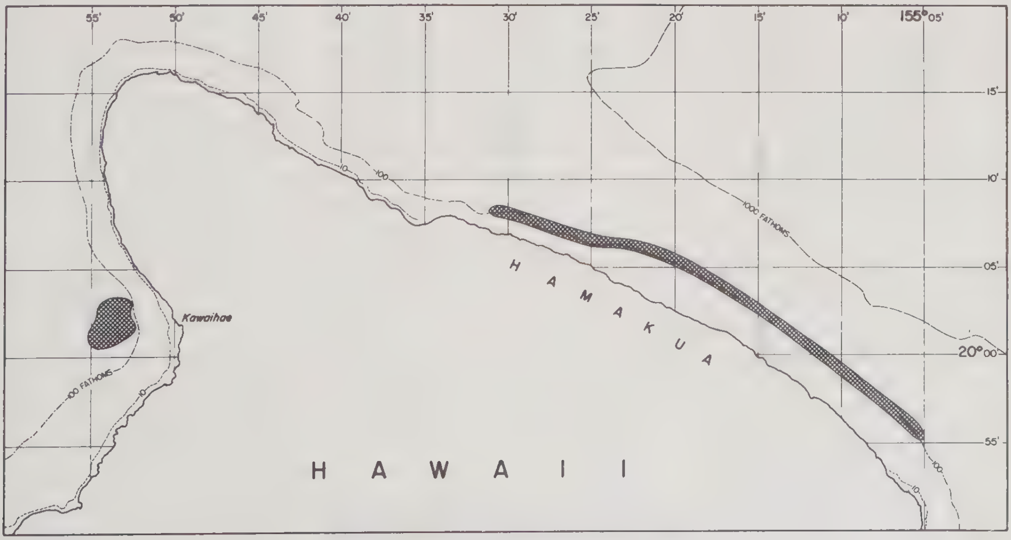

Figure 7.—Trawlable areas off the Island of Hawaii.

human activity. The best catch of *P. marginatus* was 7 pounds (3.2 kg) for a 1-hour daylight tow in 122 fathoms (225 m) during 1972. No catches of *P. marginatus* were made in the following three areas.

Kalohi Channel

A small portion of western Kalohi Channel was found to have a smooth mud bottom (Fig. 3). The trawlable area is bounded on the north, east, and south by the base of the recent shelf break at about 125 fathoms (230 m). The floor of the channel slopes gently westward to about the 165-fathom (330-m) curve where the bottom becomes broken and trawling conditions are marginal.

Kaiwi Channel

The portion of Kaiwi Channel between Honolulu Harbor and Makapuu Point (Fig. 5) was found to be trawlable in depths greater than about 300 fathoms (550 m). One tear-up was experienced when rough bottom was encountered at about 275 fathoms (500 m) on the north edge of Penguin Bank.

Kawaihae

A small trawlable area of smooth, sandy mud bottom in the 130-220 fathom (235-400 m) depth range was located due west of Kawaihae (Fig. 7). The 50-300 fathom (90-550 m) depth range off this coast between lat. 19°50′N and Malae Point (lat. 20°06′N) was extensively surveyed. Bottom conditions, for the most part, are very rough with reliefs of 25-30 fathoms (45-55 m) common in the 190-300 fathom (350-350 m) depth range. Bottom recordings indicated very heavy concentrations of fishes associated with the pinnacles in this region; limited attempts to sample these populations with traps and handlines were unsuccessful.

Other Species Taken In Trawls

Several other species of shrimp were taken in small amounts in the deeper trawling areas south of Oahu (Fig. 5), off north Maui (Fig. 4), and south of Lanai (Fig. 6). They generally occur deeper than 150 fathoms (275 m) and the problem of sorting them from the numerous fishes also taken in these depths renders trawling an impractical means of harvest. The penaeid *Aristeus semidentatus* was taken in small numbers, with catches ranging up to about 2 pounds (1 kg) per hour. Only slightly better catches were made of the caridean shrimps *Heterocarpus ensifer* and *H. laevigatus*, but they are readily taken in traps (Struhsaker and Aasted, 1974). Several small species belonging to the genera *Pandalus* and *Pleisioneka* were also present in small amounts in all of the deeper tows.

Incidental catches of other crustaceans were also made. During fall 1968 white crabs, *Portunus sanguinolentus*, were taken at every station off Haleiwa in depths of 54-66 fathoms (99-121 m) with catches ranging up to about 30 pounds (13.6 kg) and averaging 13.5 pounds (6.1 kg) per tow. This species was also present in every station off northwest Molokai in depths of 65-68 fathoms (120-124 m). Catches were smaller, however, averaging 5.8 pounds (2.6 kg). The size of the crabs ranged from about 3 to 7 individuals per pound (6-15 per kg).

During fall 1968, slipper lobsters, *Scyllarides squamosus*, were present at 6 of 11 stations off northwest Molokai. From 1 to 4 individuals were taken per tow and weighed 1-2 pounds each. At the same time six spiny lobsters, *Panulirus marginatus*,[1] were taken at three stations. Finally, individual kona crabs, *Ranina serrata*, were taken on several occasions at depths of 100 fathoms on the north edge of Penguin Bank. These catches are of interest primarily from the standpoint of depth records for these species: perhaps trap fishing at these depths would prove to be commercially feasible.

In the Pailolo Channel areas, several species of fishes were taken that might be sold in local markets. These incidental catches usually ran about 40-60 pounds (18-27 kg) per 2-hour drag. Small flatfishes of the genera *Taeniopsetta*, *Parabothus*, and *Arnoglossus* made up most of the finfish catch. Papio, *Caranx* sp.; aweoweo, *Priacanthus* spp.; and boarfish, *Antigonia steindachneri* were also taken in small amounts.

On the Molokai side of Pailolo Channel, dead "trees" of black coral, *Antipathes* sp., were often taken in the trawls: catches of 25 pounds (10 kg) were not unusual.

Variation In Catch Rates

The reasonably accurate station position data obtained during the surveys permit an examination of the effects of time of day, depth of water, and towing speed on the catch rates of *Penaeus marginatus*. Only quantitative stations with a 41-foot 4-seam flat shrimp trawl (without mud rollers) from the first four cruises are considered. The estimated area sampled by a trawl was converted to hectares and catch rates are expressed as numbers of shrimp per hectare. The time of the station is considered to be the median between on- and off-bottom times.

It soon became apparent during the early cruises that the catches of *P. marginatus* varied markedly by time of day and depth of water fished. While catches were made at night in the shallower areas, shrimp were taken during both day and night in depths of 110-125 fathoms (200-230 m). However, in these deeper areas, daytime catches were higher than those of night catches (Table 1).

The effects of time of day and depth of water are summarized in Figure 8, where average catches are given for five depth zones for 3-hour periods throughout the day. Sampling effort ranged from one to nine stations for each combination of the two factors. Unfortunately, there is no extensive area in the Hawaiian Islands that permits a continuous series of trawling stations over the entire depth range inhabited by *P. marginatus*. Therefore, the data for the five depth zones treated are for five geographical areas.

The deepest depth zone of 110-125 fathoms (200-230 m) is represented by catches obtained at 42 stations in Pailolo Channel. For each time period, the catches for both the Maui and Molokai side of the Channel were averaged together. Although the catches were usually higher on the Molokai side, the day-night patterns in catch rates for the two areas were similar. Although shrimps were taken at all times of the day, catches were highest during daylight hours and considerably reduced during night.

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[1] This endemic species was long known as *P. japonicus* but was recently referred to *P. marginatus* (Quoy and Gaimard) by George and Holthuis (1965). Brock (1973) recently reported the species from Johnston Atoll.

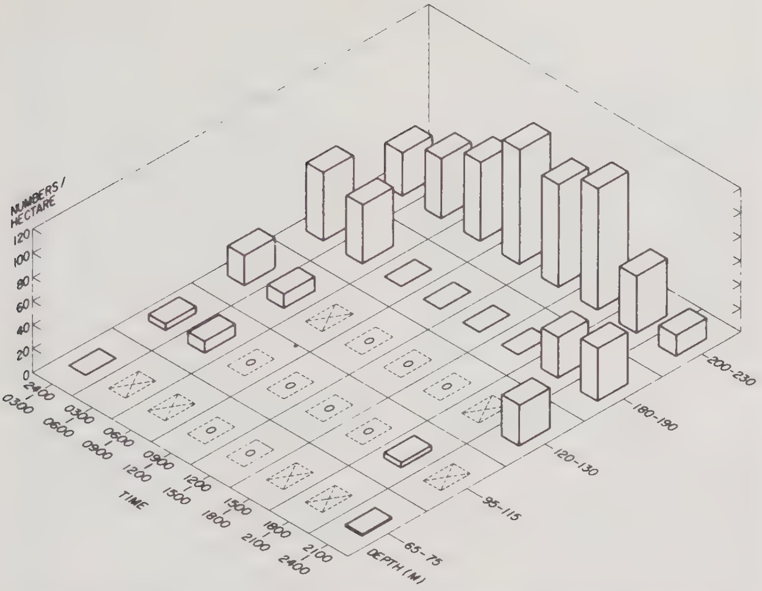

Figure 8.—Average catch rates (numbers per hectare) of *Penaeus marginatus* by time of day and depth. Cells with a dashed rectangle and an "O" indicate that no *P. marginatus* were taken for that combination of factors, while rectangles with an "X" indicate that no sampling was conducted for that combination of factors.

The data for the 99-104 fathom (180-190 m) depth range were obtained from 41 stations in the Penguin Bank area where the best catches were made at night. Only a few shrimps were taken during daytime, and catch rates averaged less than one shrimp per hectare.

The 65-70 fathom (120-130 m) depth range is represented by the northwest Molokai area where 22 stations were made. Shrimps were taken only during 2100-0600 hours. No stations were made during 0600-0900 hours and 1800-2100 hours, and while sampling was conducted during the three time periods between 0900 and 1800 hours, no shrimps were taken.

A total of 23 stations in the Haleiwa area provide the data for the 53-63 fathom (95-115 m) depth range. No daylight catches of shrimps were made and only small catches were made at night. No median sampling times fell within the 2100-2400 hours time period.

Five stations, all off north Maui, were made in the 35-40 fathom (65-75 m) depth range. Only small amounts of shrimps were taken during night in these depths.

We believe that the pattern of catches of *P. marginatus* can best be explained by a nocturnal movement of the shrimp into shallower depths. In the areas considered, the slope of the bottom is such that the shrimps would have to undertake horizontal movements of only about 1 mile (1.9 km) to effect depth changes of 40 fathoms (75 m). This is indicated by the reduced night catches in the deepest depth zone, higher night catches in the next deepest zone, and progressively smaller catches in each succeeding depth zone. As pointed out by Pearcy and Laurs (1966), strong evidence for vertical migration in midwater animals is provided in a case where daytime catches of an animal exceed those of the night catches in the same depth zone. Presumably, the animals can better avoid the trawl during daylight; thus, reduced nighttime catches are indicative of movement out of the depths being sampled.

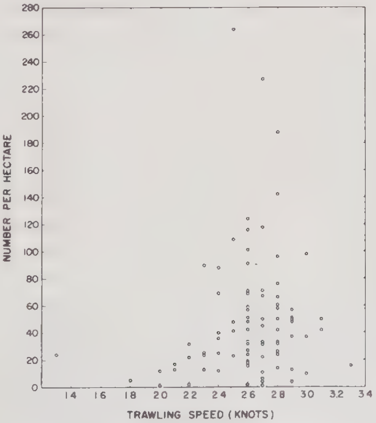

Figure 9.—Number of *Penaeus marginatus* taken as a function of trawling speed.

Thus *P. marginatus*, like most other species of the genus, appears to be negatively phototactic (avoids light). However, it seems as though most individuals of *P. marginatus* accomplish this by moving offshore into deeper water during daytime, rather than burrowing during daylight hours as do most other species of *Penaeus*. However, captive specimens of *P. marginatus* have been observed to burrow readily, and burrowing may also be an important behavioral component of this species. As discussed below, smaller shrimps occur in shallower depths. Possibly the smaller shrimps undertake more limited movements offshore and, burrow to some degree. If the smaller shrimps occurring in the shallower depths burrowed during daytime and did not undertake any migratory movements, then we would expect to occasionally capture a few shrimps during daylight stations. However, not one *P. marginatus* was taken between 0600 and 1800 hours in depths of 70 fathoms (130 m) or less.

We also examined the effect of trawling speed on the catch rates of *P. marginatus*. Figure 9 shows the relationship between catch and towing speed for 83 stations. Zero-catch stations were not plotted. The optimum towing speed appears to range from about 2.3 to 3.0 knots, with the best catches being made at 2.5 to 2.8 knots. There is considerable variation in catch rates within the indicated optimum towing speeds. This is due to variation in the abundance of shrimps by depth and time of day as discussed above. We assume that at lower trawling speeds the shrimps avoid the trawl more readily, and at higher speeds the trawl lifts off the bottom, permitting the shrimp to escape under the trawl.

GENERAL OBSERVATIONS

At each station where *P. marginatus* was taken, the shrimp were counted and weighed. At 63 stations where the catch exceeded 5 pounds, the shrimp ranged from 14 to 23 individuals per pound (heads-on). Shrimp in most of the catches (45 stations) ranged from 16 to 19 per pound, and the average for all stations was 17.7 per pound.

The percentage of the total weight of the shrimp contributed by the tail (shell on) was determined at eight stations; the tails make up 50 percent to 55 percent of the total weight.

The total lengths (tip of rostrum to tip of telson) were determined for many specimens of *P. marginatus*. Length frequencies for three stations are presented here to illustrate the main conclusions resulting from analysis of these data. At all stations during the surveys, female shrimp ranged to a larger size than the males (Fig. 10). The shrimp taken in the shallower portions of the Haleiwa area tended to be smaller than those from Pailolo Channel. Finally, there were no obvious seasonal differences in the size of shrimp inhabiting depths of 100-125 fathoms (185-230 m). This is shown for the Pailolo Channel in Figure 10, where a sample collected during fall (C and D) is compared with one collected during spring (E and F).

Although the numbers of male and female shrimp are about equal in lesser depths, the males consistently outnumber the females by ratios of 3-4 to 1 in depths of 100-125 fathoms (185-230 m). This is illustrated in Figure 10, for which random samples from Haleiwa (A and B) and Pailolo Channel (E and F) are presented. The other Pailolo Channel sample in the figure (C and D) is not a random one.

MAGNITUDE OF THE RESOURCE

An estimate of the standing biomass of *P. marginatus* available at any one moment on the four most productive fishing grounds was made by determining average catch rates per unit area (for fall 1968) and the area of each ground. A summary of these estimates is as follows: Pailolo Channel-Molokai side, 8,316 pounds (3,780 kg) for 4.0 square miles (13.7 km^2); Pailolo Channel-Maui side, 2,367 pounds (1,076 kg) for 3.0 square miles (10.2 km^2); Penguin Bank, 3,294 pounds (1,497 kg) for 3.0 square miles (10.3 km^2); Molokai, 1,784 pounds (811 kg) for 5.5 square miles (18.7 km^2); all four areas, 15,761 pounds (7,164 kg) for 15.4 square miles (52.9 km^2).

Although this standing biomass estimate of about 16,000 pounds (7,270 kg) is not impressive, it is a minimal estimate of the available resource for the following reasons. 1) There is no allowance in the estimate for trawl avoidance by the shrimp. 2) The available trawling areas of the four most productive grounds can probably be enlarged. 3) Additional trawling grounds appear available. 4) There may be movement of adults from untrawlable areas to the fishing grounds. 5) There is some evidence that this species spawns throughout the year. 6) Recruitment of young could be provided by adults inhabiting untrawlable areas.

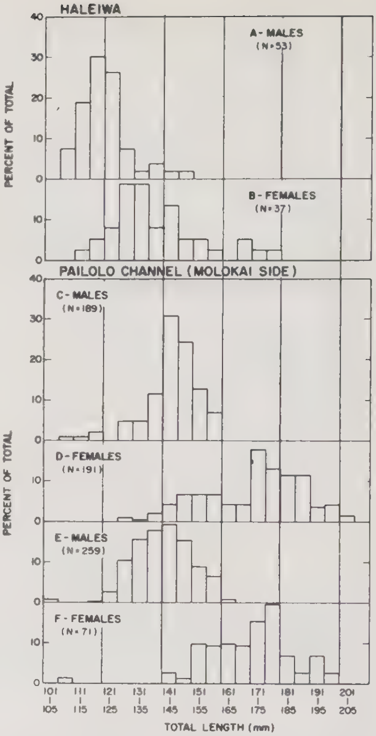

Figure 10.—***Penaeus marginatus*** **length-frequency data. A and B: Haleiwa area, 65-80 fathoms (118-146 m), October 1972. C and D: Pailolo Channel (Molokai side), 110-120 fathoms (201-219 m), October 1972. E and F: Same as preceding, March 1971.**

In order to gain some idea of the total magnitude of the *P. marginatus*

Table 2.—Estimated areas of seven depth ranges in the Hawaiian Islands. Units are square nautical miles and kilometers (in parentheses). See text for further explanation.

Region	Depth range													
	Fathoms 0-10 Meters 10-20		10-100 20-200		100-200 200-400		200-300 400-600		300-400 600-800		400- 500 800-1,000		500-1,000 1,000-2,000	
Leeward Islands														
Kure Is.-Laysan Is.	308	(1,056)	979	(3,358)	343	(1,176)	131	(449)	222	(761)	290	(995)	1,797	(6,164)
Maro Reef-Gardner Pinnacles	114	(391)	1,347	(4,620)	317	(1,087)	357	(1,225)	297	(1,019)	456	(1,564)	3,368	(11,552)
St Rogatien Bank-Nihoa Is.	109	(374)	1,257	(4,312)	871	(2,988)	881	(3,021)	485	(1,664)	587	(2,013)	1,980	(6,791)
Total: Leeward Is.	531	(1,821)	3,583	(12,290)	1,531	(5,251)	1,369	(4,695)	1,004	(3,444)	1,333	(4,572)	7,145	(24,507)
Main group														
Kaula Is., Niihau, and Kauai	82	(281)	225	(772)	83	(285)	176	(604)	198	(679)	228	(782)	862	(2,957)
Oahu	105	(360)	163	(559)	127	(436)	264	(906)	265	(909)	454	(1,557)	173	(593)
Molokai	51	(175)	447	(1,533)	177	(607)	296	(1,015)	247	(847)	239	(820)	411	(1,410)
Maui	48	(165)	296	(1,015)	163	(559)	267	(916)	127	(436)	76	(261)	447	(1,533)
Lanai	13	(45)	120	(412)	133	(456)	120	(412)	213	(731)	79	(271)	127	(436)
Kahoolawe	12	(41)	77	(264)	29	(99)	16	(55)	15	(51)	16	(55)	91	(312)
Hawaii	63	(216)	274	(946)	255	(875)	232	(796)	184	(631)	256	(878)	1,096	(3,759)
Total (main group)	374	(1,283)	1,602	(5,501)	967	(3,317)	1,371	(4,704)	1,249	(4,284)	1,348	(4,624)	3,207	(11,000)
Grand total	905	(3,104)	5,185	(17,791)	2,498	(8,568)	2,740	(9,399)	2,253	(7,728)	2,681	(9,196)	10,352	(35,507)

resource, as well as for other studies, we estimated the total amount of bottom area in the Hawaiian Islands for seven depth ranges to a depth of 1,000 fathoms (2,000 m). These estimates were obtained by contouring National Ocean Survey nautical charts (nos. 4115-4117 and 4181-4183) at the desired depths and then cutting out and weighing each depth range. The weights for each depth range were converted to area by reference to the weight of a known rectangular area for each chart. Checking this method by estimating known land areas indicated an error of less than 0.1 percent. The results are given in Table 2. Due to the subjectivity in plotting the contours, we feel that simply doubling the depths in fathoms to obtain depths in meters is justified.

To estimate the amount of bottom area that could be inhabited by adult *P. marginatus* in the island areas from Oahu to Hawaii, we assumed that 35 percent and 20 percent of the bottom areas in the 10-100 fathom (20-200 m) and 100-200 fathom (200-400 m) depth ranges respectively are available to this species. This results in an estimate of about 850 nautical square miles (2,915 km^2). Using an average standing biomass estimate of 1,023 pounds per square nautical mile (135 kg/km^2) from the four most productive trawling areas results in a total biomass estimate of about 870,000 pounds (395,500 kg) of *P. marginatus*. Considering the factors discussed above, it would not seem unreasonable to assume that 50,000 to 100,000 pounds (23,000 to 46,000 kg) of this species might be harvested annually.

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RECENT DEVELOPMENT IN FISHERIES FOR SKIPJACK TUNA, *Katsuwonus pelamis*, IN THE CENTRAL AND WESTERN PACIFIC AND THE INDIAN OCEAN

by

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1. INTRODUCTION

At the World Scientific Meeting on the Biology of Tunas and Related Species held at La Jolla, California in July 1962, Chapman (1963) stated: "In the United States the market for canned tuna has a little more than doubled every ten years for the past fifty years and is still increasing at about the same rate." The world tuna production reached roughly 400 000 tons in 1950 and close to 800 000 tons by 1960. By 1970, Chapman estimated the world tuna market would require about 1 500 000 tons of tuna. Chapman's estimate was remarkably close. In 1970, according to FAO statistics (FAO, 1972), the world's production of tuna and tuna-like fishes reached 1 427 000 tons.

Roughly half of the 1970 production consisted of yellowfin tuna (Thunnus albacares), and skipjack tuna (Katsuwonus pelamis), but yellowfin tuna production appears to be stabilizing and a substantial increase in catches of this species seems unlikely. Intensive investigations by the Inter-American Tropical Tuna Commission (IATTC) demonstrated that there was a need to implement conservation measures for yellowfin tuna in the east Pacific fishery. This led to regulation of the yellowfin tuna stocks in the east Pacific (Joseph, 1970). Kamimura (1966) has also shown that increases in effort for yellowfin tuna in the longline fishery beyond the 1962 level would not increase the catch.

Concerning skipjack tuna, the apparent abundance has not been affected despite the large catches (Broadhead and Barrett, 1964; Kawasaki, 1965; Rothschild and Uchida, 1968). In 1960-73, the east Pacific fishery produced catches that ranged between 31 933 and 122 381 metric tons (t) and averaged 68 691 t (Table 1). In the west Pacific, Japanese catches in the coastal and southern water fisheries have varied from 78 608 to 201 000 t and averaged 145 110 t. The frequently made observations that there are no observable effects of fishing on the established fisheries in Japan or the coasts of the Americas and that there is sizable potential skipjack tuna yield, have induced the tuna-producing nations to turn to this species for increased production.

Essentially, the major effort in the tremendous expansion of skipjack tuna fishing has come from Japan. Realizing that no large increase in yield can be expected from the large tunas, the Japan Fisheries Agency announced a policy of skipjack tuna development on a large scale. In the opinion of some Japanese scientists, effort should not be expended to further develop the Japanese coastal skipjack tuna fishery or the present southern water fishery operating in the Bonin, Mariana, Caroline, and Marshall Islands (Kasahara, 1971; Kawasaki, 1972). The expansion, they feel, should concentrate on developing new fishing grounds in distant waters. As early as 1967, the Japanese were actively pursuing the formation of cooperative surveys with foreign governments (Katsuo-Maguro Nenkan, 1973). For example, with the signing of the Japan-Australia Fishing Treaty in 1968, the Japanese began fishery surveys which eventually led to formation of joint ventures in Papua New Guinea.

This report reviews areas of the central and west Pacific and the Indian Ocean where fisheries for skipjack tuna have developed in recent years or where the potential for skipjack tuna fishery expansion or development lies. Geographically, the coverage is fairly extensive with major emphasis on the Pacific islands ranging across the tropical Pacific from Indonesia to the Marquesas Islands. The Japanese coastal and southern water fisheries and the east Pacific fishery within the scope of IATTC, both well documented in the literature, have been omitted.

2. CENTRAL PACIFIC OCEAN

The present theory of stock separation and migration is that the skipjack tuna population in the Pacific is composed of a west Pacific stock that ranges from the Philippine Sea to Japan and from the Ryukyus south to New Guinea and into the Coral Sea, and a central Pacific stock that probably extends from the Carolines and the eastern portion of the Marianas to the Americas (Fujino, 1967, 1970, 1972). More detailed information on the stock composition in the west and central Pacific is given in the second part of the present document prepared by Kearney.

For convenience, the Pacific islands and nations dealt with in this review have been divided into two groups. Those lying between 130°W and 180°W were classified under central Pacific; those from 180°W to the islands bordering the Indian Ocean were considered in the west Pacific. The groups in the central Pacific include the island groups of French Polynesia, the Hawaiian Islands, Samoa Islands, and Tonga Islands (Figure 1).

2.1 French Polynesia

The island groups in French Polynesia include the Society, Tuamotu, Gambier, Rapa, Austral, and Marquesas Islands. Tahiti, in the Windward Islands of the Society group, is the only island in French Polynesia with a small commercial fishery for skipjack and yellowfin tunas. The fishery was described in detail by Van Campen (1953) and Van Pel and Devambez (1957).

Briefly, Tahitian fishermen use small, fast boats called "bonitier" (Brun and Klawe, 1968). These diesel-powered craft, measuring about 9 m in length, can accommodate three men. No refrigeration is used; therefore, each boat returns in the afternoon to unload its catch.

The fishermen locate schools of yellowfin and skipjack tunas by scouting for bird flocks. Also, in recent years trolling lines have been used when searching for surface schools (Brun and Klawe, 1968). When a school is encountered, the boat is kept underway and moving with the school. The fishermen, using pole and line to which a pearl-shell lure is attached, slap and drag the lure on the surface of the water until the fish strikes. The hooked fish is flipped into the boat cockpit. In order to return the hook to the water as rapidly as possible, the fishermen shake the lure loose, disengaging the hooked fish while it is in the middle of its trajectory.

The growth of this fishery is reflected in the steady increase in the number of boats employed. Figure 2 shows that only 15 boats were fishing in 1954 but by 1967 there were 107 (Brun and Klawe, 1968). The fleet size has apparently stabilized; in 1972 there were 97 skipjack tuna fishing boats involved in pearl-shell lure fishing (Doumenge, 1973).

Doumenge (1973) reported that not all Tahitian bonitier go out to fish regularly. About half fish full time; others are idled periodically either for want of crew or for maintenance. Some boats operate only part time when the market is glutted and prices are low.

Figure 2 also shows that in 1954-67 the landings of tuna increased with the number of boats engaged in the fishery (Brun and Klawe, 1968). In this period, annual skipjack tuna landings fluctuated between 252 and 731 t and averaged 379 t. Annual landings of yellowfin tuna were smaller and varied from 41 to 126 t, averaging 77 t.

The skipjack and yellowfin tuna landings shown in Tables 2, 3, and 4 actually represent only about a third to a half of the true production of tuna from Tahiti. There are two important sources of error: first, because the fish are gilled and gutted at sea, the landings at Papeete Municipal Market represent weights of eviscerated fish (Brun and Klawe, 1968); and secondly, many fishermen dispose of their catches directly to local fish dealers or through roadside and door-to-door sales (Doumenge, 1973). The result is that only the surplus is sold through the Papeete Municipal Market; thus, the true production is considerably higher than the reported landings.

In 1972-73, to determine the feasibility of catching surface schools of skipjack and yellowfin tunas by pole and line and live bait in French Polynesian waters, the Service de la Pêche, Polynésie Française (Fisheries Department of the Territory of French Polynesia), arranged to have three bait boats carry out fishing trials (U.S. National Marine Fisheries Service (NMFS), 1972g; Doumenge, 1973). These trials, although involving mostly the Windward Islands, were also extended to the Leeward Islands and parts of the Tuamotu and Marquesas Islands.

The results of these trials are summarized in Tables 5 and 6. Initial catches of the fishing boat MOETU in the Windward Islands in February–June 1972 were not encouraging. Catch per trip averaged only 0.3 t in 28 trips. In December 1972–February 1973, however, the Hawaiian pole-and-line boat, ANELA, did very well. Despite difficulty in obtaining enough live bait to fish continuously (Captain George Higashide and crew, c/o Hawaiian Tuna Packers, P.O. Box 238, Honolulu, Hawaii 96809, personal communication), ANELA logged 19 trips and caught an average of 5.4 t per trip. REDONDO, the third boat engaged, fished on five trips in March–April 1973 and produced about 1 ton per trip.

In 20 trips to the Leeward Islands, MOETU caught an average of 0.6 t per trip which was considerably better than the catch rate in the Windward Islands during the same period (Doumenge, 1973). ANELA, in six trips, confirmed the excellent prospects of the Leeward Islands fishing ground by producing an average of 3.0 t per trip.

Fishing in the Tuamotu Islands proved disappointing (Table 5). MOETU produced less than 0.1 t per trip and ANELA caught only 0.2 t per trip. In the Marquesas Islands, however, six fishing trips by ANELA yielded an excellent catch per trip of 4.7 t.

These fishing trials gave ample indication of tuna but not of a sustained abundance of baitfish. ANELA found bait supplies limited and most of the bait used were juveniles of the scad mackerel (Trachurops sp.) and jacks that were caught by night baiting. Many problems need to be solved before a commercial pole-and-line, livebait fishery can be successfully established in French Polynesia.

2.2 Hawaiian Islands

The fishery for skipjack tuna in the Hawaiian Islands has been adequately described in a number of publications (June, 1951; Yamashita, 1958; Uchida, 1966). Briefly, it is a pole-and-line fishery that began about 1900. The introduction of Japanese fishing sampans and gear brought about a rapid growth of the fishery and by 1928 a little over 2 000 t of skipjack tuna were being landed. Nowadays, the Hawaiian fleet, composed of 16 sampans of various sizes, lands about 5 000 t of skipjack tuna annually (Table 1).

Of primary concern at the present time is the expansion and development of the fishery. Purse seining was tried in Hawaiian waters in the early fifties (Murphy and Niska, 1953) and recently another attempt was made (Hawaii Division of Fish and Game and Bumble Bee Seafoods, 1970) but these trials were only partially successful. Thus, pole-and-line fishing with live bait is still the preferred method in Hawaiian waters. At present the industry faces a two-fold problem: first, the need to upgrade the entire fishing fleet; and secondly, the need to increase the supply of live bait.

The Hawaiian skipjack tuna fleet consisted of 28 fulltime vessels during the fifties. Between 1955 and 1971 the demand for tuna increased steadily but even this failed to induce any investment in new fishing vessels and the fleet dwindled to 14 in 1971. The following year, however, reflecting changing enonomic conditions and favourable minimum prices, a 136-gross ton (GT) steel-hulled vessel with a cruising speed of 13.8 kn and a cruising range of 2 000 n mi (3 700 km) joined the fleet (Uchida and Sumida, 1973).

A fluctuating supply of live bait continues to limit the expansion of the skipjack tuna fishery. In 1960–72, the fleet caught an average of 33 659 buckets of nehu (Stolephorus purpureus), a local anchovy that is the preferred bait of the Hawaiian fishermen (one bucket contains about 3.2 kg of nehu). Periodic shortages of bait reduce fishing time. Furthermore an increase in demand for bait can be expected because rising costs of new vessel constructi and operations will undoubtedly force the owners to operate their vessels on a year-round basis.

In an attempt to alleviate the bait shortage, the Honolulu Laboratory of the National Marine Fisheries Service, Southwest Fisheries Center, has investigated a number of options. Among them have been the culture of baitfish and the transporting of live bait from areas of abundance to areas of scarcity. Experiments in transporting live anchovy (*Engraulis mordax*) from California to Hawaii are continuing at the present time.

2.3 Samoa Islands

Samoa Islands, divided into American Samoa, a U.S. territory administered by the U.S. Department of the Interior, and Western Samoa, an independent sovereign state, are situated between latitude 13° and 15°S and extend in an east-west direction from about longitude 168° to 173°W (Tudor, 1972). American Samoa is comprised of all islands lying east of longitude 171°W. Pago Pago on the island of Tutuila is the principal town. Western Samoa has two large main islands - Upolu and Savaii. The chief town and administrative centre is Apia on Upolu. Pago Pago Harbor serves as a port of landing for foreign longline vessels, now mostly Chinese and Korean, which supply two American canneries with large, subsurface tunas (Van Campen, 1954; Otsu and Sumida, 1968; Uchida and Sumida, 1973).

In an effort to develop a viable pole-and-line skipjack tuna fishery in American Samoa, the Office of Marine Resources (OMR), Government of American Samoa, has launched an investigation to determine temporal and spatial distribution and abundance of skipjack tuna and baitfishes in Samoan waters (Swerdloff, 1974). In October 1971, OMR acquired a new 15.2-m livebait vessel the ALOFAGA. This survey vessel is equipped with four baitwells, fishing racks, ice holds, and has a range of 1 500 n mi (2 780 km) at a cruising speed of 10 kn.

All bait surveys conducted in Samoan waters to date have revealed a scarcity of live bait (Hida, 1970; Uchida and Sumida, 1973; Swerdloff, 1974). According to Hida, baiting was best in Pago Pago Harbor. The results of day and night baiting in Pago Pago Harbor and in Apia Harbor, Western Samoa, are summarized in Table 7.

To determine the seasonal fluctuations and relative abundance of baitfish in Samoan waters, OMR conducted not only visual surveys of all bays and estuaries but also sampled baitfish that collected around a night light. The results are shown in Table 8. In all sampling conducted since August 1970, the annual catch per set has never exceeded 3.0 buckets. Whereas in August-December 1970 *Stolephorus* sp. predominated in the catch, there has been a steady deterioration of catches of this species in subsequent years.

The scarcity of bait severely handicapped the efforts of ANELA to conduct pole-and-line fishing trials for skipjack tuna in Samoan waters in March-April 1972 (Uchida and Sumida, 1973). ANELA was unable to locate, either day or night, any bait in sufficient amounts in all of the bays and harbours surveyed in both American and Western Samoa. Bait taken in Fiji by ANELA was used to fish in Samoan waters.

The results obtained from the RV CHARLES H. GILBERT, ANELA, AND ALOFAGA survey cruises were ample evidence that skipjack tuna schools occur in Samoan waters in sufficient quantities to support a commercial fishery at least large enough to meet local demands. Waldron (1964) showed that sightings of bird flocks averaged 4.2 flocks per 10-hour period in December-February in 26 hours of scouting. Hida (1970) reported sighting 144 schools in 31 days of scouting and fishing or an average of 4.6 schools per day (Table 9). In March-April 1972, ANELA sighted 25 schools in Samoan waters or an average of 6.2 schools per day (Uchida and Sumida, 1973). Sixteen were identified as skipjack tuna, 1 as kawakawa (*Euthynnus affinis*); the remainder were unidentified.

Concerning catches, Hida (1970) reported that GILBERT successfully fished 16 schools around American and Western Samoa and caught 1 075 skipjack tuna varying in size from 1.8 to 7.7 kg and 160 yellowfin tuna ranging between 1.1 and 27.2 kg. Twelve of the 144 schools sighted during the GILBERT cruise were estimated to be large, possibly over 45 t (Table 10).

In 4 days of scouting (3 days of actual fishing), ANELA encountered 25 schools. Of these, 21 were pursued and chummed but only 8 were successfully fished. Total catch reached 2 407 skipjack tuna weighing 12.1 t and 33 kawakawa. Catch per day averaged 4.0 t. About half of the catch consisted of fish under 4.5 kg although the fish landed ranged from 2.3 to 11.6 kg. Hooking rate was calculated to be from 0.2 to 2.0 fish per hook-minute.

The results of the nearshore surveys conducted by OMR have shown that a skipjack tuna resource of considerable potential exists in Samoan waters (Swerdloff, 1974). School sightings compare favourably with those of the Hawaiian skipjack tuna fishery and the fishing trials conducted by ANELA showed that skipjack tuna are present in sufficient quantities to support a commercial fishery (Uchida and Sumida, 1973). Shoreside ship-servicing facilities already exist in Pago Pago Harbor. A vital prerequisite, however, is finding the best means of catching the tuna. Naturally occurring bait is scarce but some baitfish, such as the mollie (Poecilia mexicana), could probably be cultured in sufficiently large quantities to keep a small fleet of livebait vessels operating full time (Rodman, 1974).

2.4 Tonga Islands

The Kingdom of Tonga consists of three main groups of islands; in all, there are some 150 islands with a total land mass of 257 mi^2 (660 km^2) (Wilkinson, 1973). With the population growing at an annual rate of 4 percent, there is an urgent need in the Kingdom to find sufficient animal protein food. According to Wilkinson (1973), there have been several attempts in the past to develop the fisheries of Tonga, all with varying degrees of success. At present, there is a Government-owned longliner fishing for subsurface tunas in Tongan waters. The 27-m vessel of Japanese origin has a refrigerated capacity of 45 t. The vessel is manned by a Tongan master and crew, Tongan trainee fishermen and a Japanese masterfisherman.

Trolling for pelagic species is carried out by sailing vessels and good catches of skipjack tuna and kawakawa are possible seasonally. Wilkinson (1973) lists the development of a skipjack tuna fishery as one of the priorities of the Government. He states: "...possible development exists in exploiting the shoals of skipjack and kawakawa, which occur in seasonal abundance in close proximity to the many Tongan islands."

According to Otsu (trip report - Trip to Japan, 3-26 February 1974), the Japan Marine Fishery Resource Research Center conducted bait surveys in Tongan waters in 1972-73. The results of the Tongan survey indicated that, among the 200-300 islets scattered throughout the archipelago, the waters around the northernmost island seemed most promising as a bait site. Using beach seines, the survey vessel caught 20-30 buckets of baitfish per set but mortalities were heavy. The Center concluded that there is very little likelihood of developing a pole-and-line fishery in Tonga.

3. WESTERN PACIFIC OCEAN

It is in the west Pacific Ocean that the most rapid development of skipjack tuna fisheries has taken place in recent years. The thriving skipjack tuna pole-and-line fisheries of Papua New Guinea, Palau Islands, and the Solomon Islands, are typical examples. Other countries are only now beginning to look seriously at their skipjack tuna and bait resources as bases for immediate or future economic development and are seeking financial aid from countries that have established themselves as leading fishing nations in the Pacific basin.

At the Thirteenth Session of the Indo-Pacific Fisheries Council held in Brisbane, Queensland, Australia in 1968, fishery development in the South China Sea in the context of a "South China Sea Fisheries Development and Coordinating Programme" was discussed (Gulland et al., 1974). The purpose was to provide a suitable mechanism for coordinating and implementing fishery development in the South China Sea region. At its Fifteenth Session in Wellington, New Zealand in October 1972, the Council unanimously endorsed a project supported by the United Nations Development Programme (UNDP) and designed to ensure the continuous and steady development of various kinds of fisheries in the region. Among the pelagic fishery resources in the South China Sea that were listed for development and management were the stocks of tuna, including skipjack.

In the west Pacific, Japan has been most active in establishing joint skipjack tuna fishing ventures with developing countries. Figure 3 shows some of the island groups and nations that are discussed in this section.

3.1 Australia

Exploratory fishing trials for southern bluefin tuna (*Thunnus maccoyii*), and skipjack tuna with pole and line and live bait in Australian waters have been described in Blackburn and Rayner (1951). In 1940, pilchard (*Sardinops neopilchardus*), and anchovy (*Engraulis australis*), were carried in a bait tank and used successfully to catch bluefin and skipjack tunas. These early results carried no great significance at that time because bait could not be obtained regularly in large enough quantities.

In 1950-51, a 19-m American-Fijian tuna clipper, SENIBUA, fished experimentally for 4 months in southern New South Wales waters to assess the value of pole-and-line fishing (Anon., 1965). Results were encouraging and the fishing industry took immediate steps to establish a pole-and-line fishery in Australia, but the mainstay of the Australian pole-and-line fishery that developed was the southern bluefin. In March 1963, to exploit the skipjack tuna that appeared on a definite seasonal pattern between Coff's Harbour (New South Wales), and St. Helen's (Tasmania), experiments with monofilament gillnets were begun and the results indicated that skipjack tuna could be taken in sufficient quantities with this gear (Temple, 1963; Anon., 1965). The early gillnet fishery for skipjack tuna was started off Lakes Entrance and Victoria and the vessels operated off the eastern coastal waters of this state. Skipjack tuna in this area were found closely associated with a warm current near the coast. The average weight taken was about 3.2 kg.

The skipjack tuna gillnet vessels varied in size from 9 to 18 m. Although power block was used in the early stages of the fishery, the fishermen later favoured the powered hauling drum and sheaves. The monofilament gillnet originally measured 604 m long and 20 m or 200 meshes deep. Mesh size was 14 cm. Later trials indicated that a net depth of 150 meshes was satisfactory for taking skipjack tuna. Usually, the crew consisted of up to three fishermen.

Heaviest catches of skipjack tuna occurred off Victoria in January and February. Interest in this fishery declined in 1964 when the monofilament gillnets, modified to fish on the bottom, were found to be effective in taking edible sharks which were much higher priced than skipjack tuna.

Thus, marketing difficulties inhibited the further development of the monofilament gillnet skipjack tuna fishery (Anon., 1965). In 1966, a 450-ton former U.S. purse seiner, ESPIRITU SANTO, was purchased by a South Australian firm. A U.S. crew spent a short time instructing Australian fishermen on purse-seining techniques (Anon., 1966). Fishing off Eden in mid-December 1966, ESPIRITU SANTO shot the net twice and netted 29 t of bluefin tuna and a little over 7 t of skipjack tuna. At the 1967 Fisheries Development Conference in Canberra, it was decided that special attention should be focused immediately on the use of purse seines for capturing skipjack tuna (Anon., 1967). The CSIRO Division of Fisheries and Oceanography estimated that prospective catches of skipjack tuna by purse seining could reach 36 300 t (Lorimer, 1970).

Catches of skipjack tuna and other tunas recorded for Australian waters for 1960-61 to 1971-72 are given in Table 11.

3.2 Fiji Islands

The Fiji group comprises 320 islands of various sizes between latitude 15° and 22°S and longitude 177°W and 175°E (Tudor, 1972). Two of the largest islands are Vanua Levu and Viti Levu on which Suva, the present capital, is located. The former capital, Levuka, on the island of Ovalau, serves as a port for foreign longline fishing vessels unloading frozen tuna for trans-shipment to canneries in the United States and Japan (Uchida and Sumida, 1973).

In 1971, the Food and Agriculture Organization of the United Nations, in accordance with its programme to determine the feasibility of fishery development among developing nations, scheduled a skipjack tuna resource survey in Fijian waters. This survey, known as the FAO/UNDP Local Tuna Project in Fiji, was conducted out of Suva, Viti Levu Island (U.S. NMFS,1971). A major Japanese fisheries firm was commissioned to undertake the survey and to provide technical training to the local fishermen. The project, originally scheduled to last one year, was extended and the tuna survey was not completed until July 1973 (U.S. NMFS, 19731).

In a paper submitted to the South Pacific Commission meeting on fisheries in Suva, Fiji in July 1973, it was reported that the vessel used by the project was of Japanese origin and typical of pole-and-line vessels operating in the west Pacific (Anon., 1973). The 40-ton SHINPO MARU was powered by a 250-hp diesel engine and cruised at 8 kn. Its operating range was 1 725 n mi (3 200 km). Three baitwells with natural circulation had a carrying capacity of about 85 buckets (bucket holds 1.8 kg of baitfish). Fishholds along both sides of the baitwells could hold 12 tons of iced fish. Crew consisted of four key personnel provided by the contractor - the vessel master, fishing master, chief engineer, and chummer - and 12 native Fijian trainees.

Bait and fishing operations have been described in detail by Anon. (1973) and Lee (1973). Briefly, three bait species were very abundant and constituted the major portion of the bait captured during the day with a beach seine. These were, in order of their predominance in the catch, sardine (Herklotsichthys punctatus), silverside (Pranesus pinguis), and anchovy (Thrissina baelama). Day bait was captured in shallow water along the beach with a Hawaiian-type beach seine measuring 73 m long and 4 m deep. The captured baitfish were then transferred to a bait receiver which was towed to the vessel for transfer to the baitwells. The sardine and silverside, making up 81 percent of the 1972 day bait catch, were hardy and withstood the transfer from seine to bait receiver to baitwell without significant mortalities. The anchovy was less vigorous; they scaled easily and mortalities were high. They constituted 19 percent of day bait catch.

At night, artificial light was used either above water or submerged to attract baitfish. When set above water a 1 000-W lamp was used and usually a liftnet was used to capture the bait congregated under the light. When a submerged light was used, lamp size was 500, 1 000, or 1 500 W. For this method of night baiting, a stick-held blanket net was used exclusively.

Night bait, captured in appreciable quantities, included the small round herring (Spratelloides delicatulus), sardine (Sardinella sirm), silverside (Allanetta ovalaua), and small anchovy (Stolephorus buccaneeri). Other species were taken in smaller quantities. Hardiest among the bait captured at night were sardine, silverside, mackerel (Rastrelliger kanagurta), bigeye scad (Selar crumenophthalmus), leatherskin (Chorinemus tol), Caranx sp., sardine (H. punctatus), and silverside (P. pinguis).

Baitfish catch amounted to 2 500 buckets in 1972. With better knowledge of the local baiting sites and increased efficiency in capturing bait the crew of the SHINPO MARU caught 4 000 buckets of bait in January-June 1973. Four baiting sites produced the bulk of the bait catch in 1972 - Momi Bay off Viti Levu, Kia Island, Savu Savu Bay off Vanua Levu, and Ono Island. In 1973, Soso Bay off Kandavu Island produced nearly half and Ovalau Island about a quarter of the bait catch.

On the exploratory cruise of ANELA, NMFS observers on board noted that bait was plentiful at Kia Island (Uchida and Sumida, 1973). In two baiting operations, the crew of ANELA spent 1.7 hours baiting and in three sets caught 269 buckets (3.2 kg of baitfish per bucket) of bait, averaging 158.2 buckets per hour and 89.7 buckets per set. About 75 percent of the bait was sardine (H. punctatus), and the remainder was silverside (P. pinguis).

School sightings were numerous in Fijian waters. Lee (1973) reported that on 29 exploratory fishing cruises made in 1972, 103 days were devoted to scouting and fishing for tuna schools. There were 653 sightings of fish schools, 38 percent of which were identified as skipjack tuna (Table 12). The average sighting per day was 6.3 schools. ANELA also found numerous bird flocks during its short trial fishing period in Fiji, sighting an average of 5.1 schools per day (Uchida and Sumida, 1973). The bird flocks associated with the fish schools were large: 56 percent were composed of 101-500 birds with noddy terns predominating.

In 1972, SHINPO MARU caught 44.7 t of fish of which about 81 percent, by weight, was skipjack tuna (Lee, 1973). The catch was up considerably in 1973 - in 6 months, from January through June, 96.2 t of fish were landed. The catch made by ANELA was also very impressive. In 2 days of intensive fishing, ANELA landed 19.1 t of skipjack tuna or an average of 9.6 t per day.

The Fisheries Division of the Department of Agriculture and Fisheries has acquired a new tuna research vessel, TUI NI WASALIWA (Anon., 1974a). Manned with a crew experienced in pole-and-line fishing operations, the vessel caught 18 t of skipjack tuna in 5 days of fishing or 3.6 t per day.

Lee (1973) reported that the size of skipjack tuna taken in Fijian waters ranged from 0.4 to 9.9 kg, a large percentage weighing less than 5 kg. ANELA encountered many schools of small fish in Fijian waters. The skipjack tuna landed ranged from 1.2 to 4.5 kg and averaged 2.9 kg (Uchida and Sumida, 1973).

The results of the FAO/UNDP Local Tuna Project and of the brief survey of ANELA strongly indicate that skipjack tuna schools occur in Fijian waters in sufficient numbers to support a small commercial fishery and the Fiji Islands, as a future fishery base for a commercial skipjack tuna fishing operation, has attracted the attention of tuna fishing and packing firms of other countries (U.S. NMFS, 1973k). A Canadian-British firm has sent a team to Fiji to promote fishery development plans which include the establishment of a fishing base at Lautoka. Also included are the employment of South Korean vessels for fishing and the construction of a cannery and cold storage. Other firms, including two U.S. tuna packers and several Japanese and South Korean firms, have also submitted fishing development plans.

3.3 Gilbert and Ellice Islands

The Gilbert group of islands, situated along the equator between latitude 4°N and 3°S and longitude 172° and 177°E, is composed of 16 islands. The Ellice group, between latitude 5° and 10°S and longitude 176° and 180°E, is composed of nine islands (Figure 3).

No commercial fishery for tuna exists in the Gilbert and Ellice Islands. Native fishermen, however, report that skipjack and yellowfin tunas are caught all the year round (Hinds, 1969). Skipjack tuna vary in size from 1.8 to 5.4 kg whereas yellowfin tuna vary between 1.4 and 36.3 kg. Despite the presence of both skipjack and mixed skipjack-yellowfin tuna schools in waters surrounding the Gilbert and Ellice Islands, the seasonality of these tuna schools is not known.

Hinds (1969) stated that the surface tuna schools around the Gilbert and Ellice Islands are fished by trolling lines, although the Polynesian method of pole-and-line fishing with a mother-of-pearl shell lure is practised in the Ellice Islands and the southern Gilbert Islands. Catches are small and usually divided among relatives and friends of the fishermen; only the surplus is sold. A marked increase in catches resulted when canoes were replaced with outboard-powered 3.6-m fibreglass hulls.

Fishing the tuna schools with pole and line and live bait is also a distinct possibility. Hinds (1969) reported that present in the lagoon at times are large schools of small fish, such as bari (Selar sp.), tarabuti (Harengula sp.), and kimokimo (Decapterus sp.), that could be used as live bait. Their seasonality and abundance, however, is uncertain.

3.4 Indonesia

The Republic of Indonesia consists of two chains of islands located in and surrounded by the Pacific and Indian Oceans. The southwest chain is made up of Sumatra, Java, Lesser Sunda Islands, and the western half of Timor (Tudor, 1972). The northeast chain consists of a part of Borneo, Celebes Archipelago, Molucca Archipelago, and Tanimbar Archipelago. The Republic of Indonesia also administers the province of West Irian.

Because of favourable environmental conditions, Indonesia has considerable fisheries resources (Zachman, 1973). Some parts of Indonesian waters are, at present, only lightly exploited. Substantial harvests can be anticipated from these areas, particularly those offshore where there is a high pelagic resource potential. Skipjack tuna, mackerel-like fishes, clupeids, round scads, and squids constitute part of the main pelagic resources. Subsurface tunas also occur in Indonesian waters. Zachman (1973) reported that, according to the Master Plan of Fisheries Development, the skipjack tuna stocks in Indonesian waters are estimated at 150 000 t.

The first fishery resource survey in Indonesian waters was carried out under the sponsorship of the UNDP in November 1969 (U.S. NMFS, 1971b). Funds for the survey, made available to Indonesia by the Government of the Netherlands through the United Nations, were intended for agricultural and fishery development (Katsuo-Maguro Nenkan, 1973). A base was established in Sorong, West Irian and Japanese fishing firms were contacted to determine their interest in carrying out the survey.

Two Japanese firms, one with a background in fishing and the other in trading, joined forces and were selected by UNDP to begin exploratory fishing (U.S. NMFS, 1971). Table 13 shows that the fleet consisted of five 110-GT pole-and-line vessels, four 10-ton bait-catcher vessels, and a 700-ton freezer mothership (Katsuo-Maguro Nenkan, 1973). The results of the 18-month survey, which began in November 1969 and ended in March 1971, were not encouraging (U.S. NMFS, 1971, 1971b). As a result, the Japanese firms entered into a second agreement to conduct exploratory skipjack tuna fishing in the Molucca Sea from a base in Ternate, Halmahera Island from April to September 1971 (Table 13). Catches averaged 3.5 t per vessel per day (Katsuo-Maguro Nenkan, 1973). At the end of the survey, which revealed that catches of more than 3 t per vessel per day were possible, a joint venture was established with 80 percent capitalization by the Japanese. Included in the provisions of the joint-venture agreement was the construction of a 500-ton capacity cold storage equipped with a 5-ton icemaking plant.

Other Japanese firms also showed strong interest in the skipjack tuna resource in Indonesian waters (Table 13). Plans were laid to establish fishing bases in Butung Island in the Banda Sea (U.S. NMFS, 1971e), at Pandiang on Sumatra Island with fishing operations concentrated in the Sunda Strait (U.S. NMFS, 1971f), and at Kendari on Celebes Island (U.S. NMFS, 1972b). Exploratory fishing was also conducted along the west coast of Sumatra Island bordering the Indian Ocean and in the Makassar Strait and the Flores Sea. The results of these latter two surveys, however, were disappointing (Katsuo-Maguro Nenkan, 1973).

Information on the operational aspects of the Indonesian skipjack tuna fishery is sparse. In the vicinity of Sorong, West Irian, the anchovy is caught by stick-held liftnets (bōuke ami) and used in livebait fishing (Katsuo-Maguro Nenkan, 1973). The vessels usually operate within a radius of about 250 n mi (460 km) of their home base. Data on annual catches of skipjack tuna are given in Table 2.

3.5 Republic of Korea

One of the countries on the periphery of the west Pacific, the Republic of Korea has a long tradition as a fishing nation. Until recently, however, Korean fisheries were usually confined to inland and near-coastal waters (Anon., 1973a). In the late fifties and early sixties, the Government intensified its effort to modernize the marine industry and the greatest expansion was concentrated in the offshore and deepsea fisheries. An example of Korea's bid to get a larger share of the offshore marine resources can be seen in the South Pacific albacore fishery operating out of a base in American Samoa. Here, the fishery was conducted exclusively by Japanese vessels in the early years but, from about 1958, more and more vessels from the Republic of Korea and Taiwan have been involved (Otsu and Sumida, 1968).

With no appreciable increase in catches of subsurface tuna possible, Korea in recent years have turned to the development of a skipjack tuna fishery. Skipjack tuna fishing is new to its fishermen (Anon., 1973a). Therefore, the Government has sought assistance from the FAO/UNDP.

Reports indicate that a Korean firm and a United States firm formed a joint skipjack tuna fishing venture in January 1972 (U.S. NMFS, 1971h). Construction of eight pole-and-line vessels in the Republic of Korea was scheduled and plans called for operations in the equatorial Pacific off the Philippine and Marshall Islands. Also included was construction of a tuna-packing plant in Masan. To support this plant, the Government of Korea requested that the Distant-Water Fisheries Training Centre, financed by UNDP, train pole-and-line fishermen (U.S. NMFS, 1972k). Training in pole-and-line fishing was also scheduled aboard Korean research vessels (U.S. NMFS, 1972a).

To conduct skipjack tuna fishing surveys, Korea's Government took delivery of two skipjack tuna survey vessels built in Japan (U.S. NMFS, 1972k). The 200-GT vessels have 1 000-hp main engines and an overall length of 35.6 m. Shipboard installations include a brine freezing system and a seawater circulating livebait well.

In January 1973 it was also reported that a fishermen's cooperative, the Central Federation of Fisheries Cooperatives (CFFC), planned to purchase eight 400-GT skipjack tuna vessels with a U.S.$ 13.3 million loan from the Asian Development Bank (Anon., 1973a).

These vessels will become part of a fleet of 20 skipjack tuna vessels that Korea hopes to acquire by 1976.

The training of deck and engine room officers has also received wide attention (Anon., 1973a). Under a UNDP-assisted programme, the FAO-administered Coastal Fishing Training Centre at Pusan has expanded its training programme to include engineers, officers, fishermen, and deckhands needed by the skipjack tuna fleet. The Coastal Fishing Training Centre and the Deep-Sea Fishing Training Centre, both originally established in Pusan under two separate FAO/UNDP projects, have been combined to form the Korean Fishing Training Centre, one of the largest and best equipped institutions of its kind in the world.

At least one Korean exploratory skipjack tuna fishing cruise has been completed. Fishing off the Bonin Islands, the Korean fishermen gained confidence in their ability to fish with pole and line and live bait (U.S. NMFS, 1973f). Forty five metric tons of skipjack tuna and albacore were landed.

3.6 New Hebrides and New Caledonia

New Hebrides consists of an incomplete double chain of roughly 80 islands extending from northwest to southeast for 450 n mi (834 km) (Tudor, 1972). New Caledonia lies south of New Hebrides and about 700 n mi (1 300 km) east of the Queensland coast of Australia.

A tuna fishing industry based at Palekula, which is southeast of Espíritu Santo, was established in 1957 (Tudor, 1972). The operating company, which has American, British, French, and Japanese capital, obtains tuna from the Japanese longline vessels based at Palekula. Here facilities also exist for slipping and repairing fishing vessels.

Water surrounding the New Hebrides and New Caledonia has been surveyed by ORSOM III (Angot, 1959). The results indicated that trolling gear was the most suitable for taking skipjack and yellowfin tunas. Yellowfin tuna were usually taken just outside the reef and skipjack tuna catches farther offshore. Angot stated that trolling catches of the ORSOM III were quite satisfactory. A commercial trolling fishery has been established in New Caledonia and the catch is sufficient to supply the demands of the Noumea market. Annual catches from New Hebrides are given in Table 2.

Angot (1959) concluded from the survey that waters surrounding New Caledonia were sufficiently productive to support a small-scale troll fishery but not a pole-and-line fishery. Very few surface tuna schools were sighted during the survey period. Furthermore, small fish that could be used as live bait were not found in sufficient quantities to permit extensive pole-and-line fishing.

In 1973, it was reported that the 190-ton Japanese pole-and-line vessel AKITSU MARU 20, was chartered by the semi-government Marine Fishery Resource Research Center of Japan to conduct surveys of baiting grounds in the South Pacific (U.S. NMFS, 1973l). In late November, AKITSU MARU caught 35 buckets of sardines and 0.9 t of skipjack tuna east of New Caledonia. Thirty six buckets of sardines were also taken in December near latitude 20°-22°S and longitude 165°-167°E. Otsu (trip report: Trip to Japan, 3-26 February 1974) reported that lift-nets used by the survey vessel produced catches of 50-100 buckets of bait per night. The baiting grounds were usually from 1 to 3 km offshore. Exploratory fishing resulted in poor catches, unlike catches reported from the previous year. The Center concluded that New Caledonia has definite possibilities for the development of a pole-and-line skipjack tuna fishery.

3.7 New Zealand

Of the nine species of tuna and tuna-like fishes found in New Zealand waters, four are readily available to the local vessels (Robert, Baker and Slack, 1972). Only two species (albacore and skipjack tuna), however, constitute the bulk of the catch. The other two (southern bluefin tuna and yellowfin tuna) appear occasionally in large numbers, but make up only a small percentage of the annual landings.

Off New Zealand's coast, skipjack tuna usually appear in summer and autumn. They are usually caught by gillnetting, trolling, and pole-and-line fishing. The average size varies from 3.6 to 4.5 kg although pole-and-line fishing has produced fish that weighed from 6.3 to 8.2 kg.

Roberts et al. (1972) reported that experienced fishermen from both Japan and the United States, working in New Zealand, have demonstrated that pole-and-line fishing is at least partially successful for taking several species of tuna. In the Bay of Plenty, small vessels have successfully fished with pole and line and live bait which was carried to sea in modified 44-gal (166-l) drums.

In February-March 1972, a pole-and-line tuna fishing survey was conducted in New Zealand waters (Webb, 1972). Among the goals of the survey were assessment of the potential of Tasman Bay pilchards and anchovies as baitfish and investigation of tuna potential offshore using longline, pole-and-line, and troll gear.

The results of the survey suggested that pole-and-line fishing would be more practical in warmer waters to the north of the Bay of Plenty rather than in the cooler southern waters (Webb, 1973). Fish in southern New Zealand waters were more agile and less inclined to school. Furthermore, weather conditions were unstable and unpredictable, thereby interfering with pole-and-line fishing operations.

The survey also revealed that baitfish were found in sufficient quantities for a limited, but profitable, bait venture (Webb, 1972a). They were distributed throughout Marlborough Sounds (down to the lower reaches) and Tasman Bay. It was estimated that the potential catch could reach 1 000 t. Baiting was possible in all untouched areas. With five baiting methods available (purse seine, lampara, bouke net, beach seine, and trap nets) weather was not a serious limiting factor in Marlborough Sounds but it hindered baiting activity in Tasman Bay.

The New Zealand Marine Department has continued to research new techniques for catching tuna in order to promote a tuna export trade. Avery (1970, 1970a) described an unusual series of experiments where monofilament gillnets were used in conjunction with sonic and other lures to capture skipjack tuna. Briefly, signals associated with the presence of tuna, such as the transmission of various dolphin signals and thrashing and fear noises of baitfish under attack were recorded. A broad sea front of about 1 n mi (37 km) was covered with sono buoys to detect the presence of schooling tuna. The recordings of the signals were then transmitted in areas where tuna were scattered in order to attract them to the point of signal, which in fishing strategy would be to the nets or longlines.

In December 1969–May 1970, the New Zealand Marine Department supplied the Whakatana commercial fishing fleet with gillnets and other equipment. Fishing with gillnets and sonic lures produced a catch of 64 t. The efforts of this fleet established the prospect of future gillnetting for skipjack tuna, possibly in other areas. The 1970–71 programme of the Marine Department emphasized further experiments in tracking and attracting tuna with sonar equipment.

3.8 Papua New Guinea

New Guinea, the world's largest defined island, consists of three territories – the Trust Territory of New Guinea, Territory of Papua, and Territory of West Guinea or West Irian (Tudor, 1972).

The Trust Territory of New Guinea is made up of the northeastern part of the New Guinea mainland together with six large islands and their numerous small neighbours. The Territory of Papua consists of the southeast section of the New Guinea mainland and adjacent islands.

In 1972, Pownall wrote: "Exploitation of skipjack and yellowfin tuna in the Bismarck and Solomon Seas promises to develop into the Territory's most profitable fishery." The development of the Papua New Guinea fishery for skipjack tuna and the associated bait fishery has been documented by Kearney (1973). Briefly, the commercial fishery for skipjack tuna in Papua New Guinea was started in March 1970 by a joint Japanese-Australian enterprise based in the northeastern Bismarck Sea (/U.S./ Bureau of Commercial Fisheries, 1970; Kearney, 1973). In the first year of operation, three 39-ton vessels working out of Kavieng, New Ireland averaged less than the break-even catch of 5 t per vessel per day. But fishing conditions appeared to be good and all indications were that the catch could be increased. By 1971, three Japanese firms were conducting exploratory skipjack tuna fishing in Papua New Guinea. Details of the joint-venture operations may be found in Katsuo-Maguro Nenkan (1973).

Catches fell below expectation in late 1971 and early 1972. Among the problems that plagued this newly established fishery were fluctuations in the availability of skipjack and of baitfish. Based on results of the first year of operation, several recommendations evolved. Among them were to continue development of skipjack tuna fishing and baiting grounds and to establish a skipjack tuna canning plant providing employment to local residents (U.S. NMFS, 1971g).

In spite of the difficulties encountered by the Kavieng operation, other joint ventures were established. A second joint venture, established initially in Manus, later shifted to Madang (Katsuo-Maguro Nenkan, 1973); another started in Rabaul at about the same time. By 1972, three Japanese-Australian joint-venture corporations were actively engaged in skipjack tuna fishing. They joined an American canning firm and a Papua New Guinea investment corporation to establish the Papua New Guinea Canning Company (PNGCC). A summary of these joint-venture operations is given in Table 14.

Catcher boats fishing in Papua New Guinea were built either in Japan or in the Ryukyu Islands (Okinawa) and crewed by Okinawan fishermen (Kearney, 1973). Each operation involves one or more motherships to receive the catches. Catcher boats vary in size; most are about 39 GT, but some are as large as 192 t (/U.S./ BCF, 1970; U.S. NMFS, 1972l; Table 14).

According to Kearney (1973), all fishing operations in 1970–71 were confined within or on the boundaries of the Bismarck Sea. The 1970 catch was restricted entirely to the northeastern sector but the expansion of the fishery in 1971 broadened the area of operation to include the eastern and southwestern Bismarck Sea. Catches from these areas are shown in Table 15. Of the three areas, the eastern sector was most productive and catches were highest from areas within 20 n mi (37 km) of the large land masses.

In 1970, with only one joint-venture company in operation, the catches of skipjack and other tunas, including yellowfin tuna, kawakawa (Euthynnus affinis), and frigate mackerel (Auxis thazard), reached 2 430 t (Kearney, 1973). Monthly landings for March-August and November-December 1970 are given in Table 16. With three Japanese firms operating in 1971, the catch increased sevenfold to 17 002 t (Table 16), but decreased to 13 124 t in 1972 (Kearney, 1974). The annual landings for 1973 have been estimated at about 28 000 t.

The seasonal nature of the fishery can be seen in the montly landings in 1971, with peak catches occurring in June-August and low catches in November-December (Table 16 and Figure 4). The average catch per vessel per day, plotted in Figure 4, varied from a high of 6.5 t in June to 2.3 t in December.

According to Table 15, skipjack tuna caught in the southwestern Bismarck Sea were usually largest, with monthly averages ranging from 3.6 to 5.1 kg. The northeastern Bismarck Sea usually had the smallest fish; they ranged from an average of 3.2 to 3.9 kg. Fishes caught in the eastern Bismarck Sea were usually intermediate in size compared to fishes from the northeastern and southwestern sectors.

Bait is available in sufficient quantities to maintain a sizable tuna industry in Papua New Guinea (Kearney, 1973). Of 300 or more different species collected from bait stations, about 10 are considered suitable as live bait for skipjack and other tunas (Kearney, 1974). Bait surveys by Japanese research vessels also indicated the presence of a number of species that possess the potential of a good baitfish; these species belonged to the families Engraulidae, Clupeidae, Dussumieridae, and Atherinidae (Kikawa, 1971).

From the inception of the fishery in March 1970 until May 1971, bait was caught during daylight by the "oikomi ami", a set net with a bag, into which fish are driven by swimmers or divers (Kearney, 1974). This bait was predominantly Gymnocaesio gymnopterus, but also caught was Pterocaesio pisang (Kearney, Lewis and Smith, 1972). Both G. gymnopterus and P. pisang are relatively abundant and tolerate handling without high mortalities.

From May 1971, baiting operations were conducted exclusively at night with bright, submerged lights and stick-held liftnets (bōuke ami) (Kearney, 1973). Stolephorus devisi was the dominant species taken by this method. This species, although excellent for skipjack tuna fishing is very delicate and difficult to transport.

The potential for future expansion of the Papua New Guinea skipjack tuna fishery appears to be excellent. The importance of baitfish in this pole-and-line fishery cannot be overemphasized and, according to Kearney (1974), the results of baitfish research have indicated that the bait resource present in Papua New Guinea waters appears adequate for considerable expansion of the fishery. Likewise, the tuna resource in waters adjacent to Papua New Guinea is large. In 491 hours of aerial surveys, an estimated 37 469 t of pelagic fish, not including bait, were observed (Kearney, 1974). The aerial survey not only revealed possible new fishing areas, but also good concentrations of species other than skipjack tuna in some areas.

3.9 Philippine Islands

The Republic of The Philippines, comprising a vast cluster of more than 7 000 islands, extends from north to south about 1 000 n mi (1 850 km) and from east to west about 625 n mi (1 150 km) (Tudor, 1972).

The early history of the pole-and-line fishery established for skipjack and yellowfin tunas in The Philippines has been adequately described by Domantay (1940, 1940a). Briefly, four vessels ranging from 24 to 40 GT were employed to fish primarily for skipjack tuna, most abundant of the tunas found in southern Mindanao, and yellowfin tuna. The area of operation included the Sulu Sea, Celebes Sea, and off Zamboanga.

Several species of Sardinella found along Zamboanga and Davao provinces were used as live bait. S. leiogaster and Scutengraulis mystax were usually preferred over other species because of their hardiness. Bait was caught in a net, locally called "sangab", which is set against the current. Several dugouts with lights attracted the bait.

Fishing at sea was the same as in many other places with sea birds guiding the fishermen to surface tuna schools. Actual fishing time on one school usually lasted 10 minutes, although it varied widely. Ice was used to preserve the catch. The skipjack tuna caught in Philippine waters never exceeded 5 kg; those caught between October and April were usually larger, weighing not less than 3 kg. Yellowfin tuna, on the other hand, were as large as 30 kg.

It does not appear that the pole-and-line fishery as described by Domantay (1940, 1940a) has changed significantly over the years. There has been, however, a recent resurgence of interest in expanding the pole-and-line fishery by securing venture capital from foreign sources. A fishery firm at Jolo, Sulu Island reportedly was seeking Japanese firms for a joint skipjack tuna fishing venture (U.S. NMFS, 1972h). Upon approval by the Japanese Government for a Japanese company to participate in this venture, it was expected that four 10- to 15-ton purse seiners would start skipjack tuna baitfish surveys in the Sulu Sea. If the baitfish resource proved adequate, pole-and-line vessels were to be chartered from Japan.

In 1973, two more Japanese firms and a Philippine corporation agreed to form a joint fishing venture based at Zamboanga, Mindanao Island (U.S. NMFS, 1973i). According to the agreement, the Japanese will provide two 39-ton catchers and a 200- to 300-ton carrier. Fishing will be concentrated in the Sulu Sea, with a first-year goal of 1 800 to 2 300 t of skipjack tuna. The catch will be processed locally and exported to Japan.

Under a UNDP-SF Deepsea Fishing Development Project, a livebait masterfisherman from France was appointed to train Filipino fishermen in pole-and-line fishing (Reyes, 1972). The project vessel, MV HASA-HASA was to be used to train the crew in catching and keeping bait and in chumming and working skipjack and yellowfin tuna schools. The project was expected to demonstrate to the Philippine fishing industry that pole-and-line fishing could be refined and further developed into an efficient means of taking skipjack and other tunas.

Table 1 shows the catches of skipjack tuna from Philippine waters in 1967-73. They varied widely from 200 t in 1970 to 3 500 t in 1972. Not all the skipjack tuna were taken by pole and line. In 1970, for example, the Philippine Fisheries Commission (1970) included in their statistics catches of skipjack tuna as follows: bagnet - 79 440 kg; hook and line - 4 000 kg; purse seine - 18 000 kg; otter trawl - 13 720 kg; and round-haul seine - 7 200 kg.

3.10 Ryukyu Islands

The Ryukyu Islands form an arc-shaped archipelago extending from southern Kyushu in Japan southwesterly toward Taiwan. The historical development of the pole-and-line skipjack tuna fishery in the Ryukyu Islands has been discussed by Shapiro (1949) and Isa (1972).

Skipjack tuna is one of the most important species taken in the Ryukyu Islands. Isa (1972) estimated that, annually, catches of skipjack tuna accounted for as little as 14 percent and as much as 69 percent of the total fish landings in the Ryukyu Islands.

Briefly, the Ryukyuan skipjack tuna fishery employs small vessels of wooden construction that vary from 10 to 53 GT (Isa, 1972). The vessels either buy live bait from independent bait fishermen or spend a day at the baiting grounds catching enough bait for a day's fishing. The common bait species used throughout the Ryukyu Islands are given in Table 17. The amount of bait used for 1966-67 is shown in Table 18. Ryukyuan fishermen generally use the "drive-in" method to catch bait but night lighting for bait is also employed to some extent.

Skipjack tuna fishing is highly seasonal. Usually the largest catches occur in July (Table 19) and the smallest catches in March (Isa, 1972).

The Ryukyuan fishery for skipjack tuna has been beset with problems of declining effort and wide fluctuations in catches. The vessels have experienced difficulty in obtaining sufficient quantities of bait and in keeping bait alive for extended periods. Furthermore, the small Ryukyuan vessels are incapable of fishing along the Ryukyu Islands chain as the Japanese vessels do. The result is that Ryukyuan vessels are unable to shift their operations with the movement of the fish on the fishing grounds. These are some of the reasons that there has been no significant growth of this fishery.

Isa (1972) pointed out that the Ryukyu's skipjack tuna fishery will not develop or expand under the present system of operation and management. There are, however, plans to obtain vessels in the 200-ton class and to operate them throughout the year in the northwestern Pacific. Bait could be obtained locally and from other sources. There are also plans to develop multi-purpose vessels capable of operating not only in the skipjack tuna pole-and-line fishery in the summer, but also in the tuna longline fishery in the winter.

Skipjack tuna landings in the Ryukyu Islands in 1921-70 are given in Table 1.

3.11 Solomon Islands

The Solomon Islands consist of 10 large islands or clusters of islands (Tudor, 1972). They lie in a double chain from northwest to southeast and extend over 900 n mi (1 700 km) of ocean. In the Solomons fishery development is being advocated to strengthen the economic base (Katsuo-Maguro Nenkan, 1973). The local Government negotiated with Japanese interests to begin a fishing survey in waters around the Solomons as a preliminary step to the establishment of a joint-venture fishing operation.

In 1971, three tuna motherships were dispatched to fishing bases established in Shortland Island, Gizo, and Tulagi (Katsuo-Maguro Nenkan, 1973). The mothership purchased skipjack tuna caught by 39- and 47-ton Okinawan catcher boats. From five boats in the initial phase of fishing in the autumn of 1971, the fleet grew rapidly to a maximum of 15 boats in the spring of 1972 (U.S. NMFS, 1972i).

The early period of the fishery was not without problems. The boats experienced good fishing the first six months of operation, averaging 5 t per vessel per day, but catches declined thereafter and bait was in short supply (Katsuo-Maguro Nenkan, 1973). By mid-1972, the Japanese firm engaged in exploratory fishing reported that catches of their vessels were below expectation (U.S. NMFS, 1972i). The majority were landing between 50 and 60 t per month with high performers catching 70-80 t and low-performing vessels only 20-30 t per month. Catches continued low until the spring of 1973, improving gradually thereafter. By August each vessel was averaging 4-5 t per day (U.S. NMFS, 1973g). Also, larger skipjack tuna moved into the fishery. Whereas 70 percent of the fish caught in July averaged 3.2 kg, most of those taken in August averaged 3.5-4.0 kg.

Despite unstable conditions, the Japanese decided to enter into a joint venture with the local Government (U.S. NMFS, 1973a). The joint-venture plans, which became effective in the spring of 1973, called for employing 12 pole-and-line vessels and 1 refrigerated carrier operating out of Tulagi and New Georgia Islands during the first year. By mid-1973, a tuna cannery with a daily production capacity of 1 300 cases was completed on Tulagi (U.S. NMFS, 1973b, 1973h). Plans also call for an increase in output to 2 000 cases a day within the next 4 years and a fleet size of 23 vessels in 5 years. Additionally, a 600-ton capacity cold storage was built on Tulagi and 300-ton capacity storages were planned for other places. The joint venture was organized so that the local Government invested 25 percent and retained the right to increase its share later. Also, over a period of 10 years, the fishing company and vessels, now in Japanese control, will revert to local control.

In 1971-73, the Solomon-based fleet landed between 4 707 and 7 643 t of skipjack tuna (U.S. NMFS, 1973j, 1974; R.E. Kearney, Department of Agriculture, Stock and Fisheries, Konedobu, Papua New Guinea, personal communication). The cannery at Tulagi has been processing the fish, packing about 200 cases per day. The outlook is optimistic. The cannery, employing native workers, may begin full-scale operation earlier than the original schedule of 1977-78. The projected catch for 1974 is 8 000 t based on the catches of about eight vessels.

3.12 Taiwan

Taiwan, situated off the east coast of the People's Republic of China, has made remarkable progress in developing its tuna longline fishery; but, like many countries presently exploiting the large, subsurface tunas, this fishery is faced with the problem that the large tuna species in all oceans are being exploited to the limit of their potential and that continued fleet expansion will not bring about a significant increase in the catch (U.S. NMFS, 1973f). Therefore, plans have been laid to enter the skipjack tuna fishery. According to a report, it is planned to build in Taiwan 50-GT skipjack tuna fishing vessels (U.S. NMFS, 1973f).

3.13 Trust Territory of the Pacific Islands

The U.S. Trust Territory of the Pacific Islands, also referred to as The U.S. Trust Territory of Micronesia, is comprised of the Caroline, Marshall, and Mariana Islands. Within a vast area of about 3 million mi^2 (10.3 million km^2) there are 2 100 islands (Rothschild, 1966).

The skipjack tuna resources of the Trust Territory region have a long history of exploitation. The pre-second world war fishery has been described in several publications (Smith, 1947; Shapiro, 1948; Wilson, 1965; Uchida, 1970). Briefly, the Japanese fishery for skipjack tuna in Trust Territory waters began in the early twenties. By the mid-twenties, information gathered by Japanese research vessels indicated that important potential for skipjack tuna fishing existed in the Trust Territory. The result was a rapid expansion of the fishery in the thirties. A peak in production, which occurred in 1937, was attributed to the operation of an unusually large number of fishing vessels (Table 20).

The outbreak of the second world war halted commercial production of skipjack tuna from the Trust Territory region. Although longline fishing for subsurface tunas was resumed soon after the war, pole-and-line fishing for skipjack tuna was not revived until 1964 (Wilson, 1963; Uchida, 1970). In that year, a United States firm established a 1 500-ton capacity freezer-storage plant at Malakal Harbor in Palau and operated a fleet of Japanese and Okinawan skipjack tuna vessels.

In April 1969, a Micronesian Agreement was concluded between Japan and the United States (U.S. NMFS, 1971c, 1972j). Under the provision of the agreement, Japanese fishing vessels were allowed to call at Truk and Ponape to purchase supplies and for rest and recreation (U.S. NMFS, 1972j). The Japanese fishing industry hoped to have its Government's survey mission study port facilities as well as the feasibility of obtaining live bait for pole-and-line fishing in that region.

By 1971, Japanese firms were actively pursuing the establishment of joint skipjack tuna fishing ventures in Micronesia. Two Japanese firms, negotiating an agreement with a Trukese businessman, began fishing out of Truk Island with two pole-and-line vessels in the 20- to 25-GT class accompanied by one mothership (U.S. NMFS, 1971d). Two other firms jointly negotiated an agreement with the local Government in Ponape and began operations with one mothership and three 30-ton skipjack tuna fishing vessels. Fishing reportedly began in late July 1971. Soon afterwards, a third Japanese firm, which was already operating eight vessels from a base in Rabaul, New Britain in New Guinea, proposed another joint venture in Ponape (U.S. NMFS, 1971e). In early 1972, the Ponape District Fishery Corporation agreed to form a partnership with still another Japanese firm. A five-man Japanese team, dispatched to survey Ponape's baitfish resources, found the outlook for skipjack tuna fishery development very favourable (U.S. NMFS, 1972c). Under the joint-venture agreement, four 39-GT skipjack tuna vessels and one 1 000-ton refrigerated mothership were to begin fishing operations in June 1972. The catch, according to the report, was to be shipped to Japan. Future plans include the construction of a cold storage and processing plant at Ponape.

By mid-1973, restrictions regarding the entry of foreign vessels into Micronesian ports were eased. The Congress of Micronesia passed legislation that opened seven Micronesian ports to foreign fishing vessels for the purpose of supplying fuel, water, and food as well as providing rest and recreation to crew members (U.S. NMFS, 1973e). The seven ports are: Tanapag, Saipan; Tomil, Yap; Malakal, Palau; Moen, Truk; Ponape, Ponape; Jabor, Jaluit; and Darrit, Majuro.

Foreign vessels fishing in and around Micronesia include those from Japan, Republic of Korea, and Taiwan. It is estimated that about 1 000 Japanese longline and pole-and-line vessels are likely to utilize Micronesian ports for their fishing operations.

There is very little information on the current availability and abundance of baitfish in the Trust Territory region. Hida (1971) published the results of a research vessel survey of bait distribution and abundance in the Trust Territory. Sardines (*Herklotsichthys* sp.) and possibly *Sardinella* sp., were found in large concentrations on Jaluit and Majuro atolls in the Marshalls. To the south and west of Truk, the islands surveyed showed no substantial amounts of bait except round herring (*Spratelloides delicatulus*). Hawaiian fishermen claim that round herring are weak bait and do not survive well in the baitwells. Other bait species found by Hida included goatfish, mostly *Mulloidichthys samoensis*, jack (*Caranx* spp.), cardinalfish (Apogonidae), bananafish (Caesionidae), silverside (Atherinidae), damselfish (Pomacentridae), and anchovy (*Stolephorus indicus*). Wilson (1971) surveyed Truk lagoon for bait and found that, among those species that could be used for bait, were snapper (*Gymnocaesio argenteus*), cardinalfish (*Rhabdamia cypselurus*), sardine (*H. melaneura*), round herring (*S. delicatulus* and *S. gracilis*), silversides (*Allanetta ovalaua* and *Pranesus pinguis*), and damselfish (*Pomacentrus pavo*). Also, in Majuro and Jaluit in the Marshalls ANELA found good concentrations of both silverside (*P. pinguis*) and sardine (*H. punctatus*) (Uchida and Sumida, 1973). At Majuro ANELA caught 205 buckets in five sets or 41 buckets per set. Baiting at Jaluit produced 189 buckets in two sets or 94.5 buckets per set.

The annual catches from the Palau skipjack tuna fishery varied between 2 942 and 8 441 t in 1966-73 (data for 1971 incomplete)and averaged 4 800 t (Table 2). Table 21 gives the monthly catches for 1966-71 whereas Figure 5 shows the average monthly catches, which ranged from 184 t in March to 821 t in July (Congress of Micronesia, 1972). In 1966-71, the number of vessels employed in the fishery never exceeded 12. Skipjack tuna sampled at Malakal Harbor by NMFS observers in 1965-67 ranged between 48 and 62 cm (Uchida, 1970). Usually, the average size tended to increase in October-January.

Recent data on fishing in the Marshall Islands are sparse. In February and again in April-May 1972, ANELA conducted fishing trials around Majuro, Arno, and Jaluit atolls (Uchida and Sumida, 1973). In February, there were several days of good fishing and ANELA landed 20.0 t of skipjack tuna and 1.2 t of yellowfin tuna. Catch per day reached 3.5 t of tuna. In April, however, ANELA found that fishing conditions had deteriorated considerably. Bird flocks were usually smaller and only 3 of the 10 schools pursued and chummed were successfully fished. ANELA caught 2.0 t of skipjack tuna and 0.6 t of yellowfin tuna. Catch per day, which reached 0.6 t, was only one sixth of the average catch per day in February.

In a move to put qualified Micronesian pole-and-line fishermen into tuna vessels they can own and operate themselves, the Marine Resources Division of the Trust Territory has designed a new steel livebait vessel which is destined to replace the wooden-hulled Okinawan-Japanese types now in use (Anon., 1974). The unique feature of this new vessel is that it was literally designed around the baitwells. The design provides for a vessel with a cruising radius of about 1 500 n mi (2 800 km) at speeds up to 9 kn. Carrying a crew of 14, the vessel will have a carrying capacity of about 29 tons in insulated holds. Unique to pole-and-line fishing boats, the new vessel will have doors cut into the hull below the waterline to allow live bait to enter the baitwells without being handled with nets or buckets during transfer.

4. INDIAN OCEAN

Accurate data on the production of skipjack tuna from the Indian Ocean are lacking. According to Shomura *et al.* (1967), there is every indication that the skipjack tuna resource is underutilized. Sivasubramaniam (1972) estimated that 41 000 to 45 000 t of skipjack tuna are taken annually from the Indian Ocean, but Kikawa et al. (1969) estimated that this ocean may be capable of yielding about 360 000 t of skipjack tuna per annum. Thus, it is highly conceivable that there is a large resource of skipjack tuna still to be harvested in the Indian Ocean.

According to Jones and Silas (1963), pole-and-line fishing is the most effective method for catching skipjack tuna in the Indian Ocean and is practised around Minicoy Island in the Laccadive Islands, around several islands in the Maldives, and in Sri Lanka (Ceylon). Because of similarities in the method of fishing for skipjack tuna among the fishermen in the Laccadives, Maldives, and Sri Lanka, the fisheries in these areas will be discussed together (Figure 6).

4.1 Laccadive and Maldive Islands and Sri Lanka (Ceylon)

The Laccadive Islands consist of a group of 14 islands and coral reefs in the Arabian Sea, about 200 n mi (370 km) off the southwest coast of India. The islands consist of two main groups: the north group, called the Amindivi Islands; and the south group or the Laccadive Islands proper. The Maldive Islands consist of 13 clusters of coral atolls in the Indian Ocean about 400 n mi (740 km) southwest of Sri Lanka, and Sri Lanka is situated in the Indian Ocean just off the extreme southeast of India. It is connected to the mainland of India by Adam's Bridge, a chain of shoals which divides Palk Strait on the north from the Gulf of Mannar on the south.

Minicoy Island in the Indian Ocean, which lies between the Laccadive and Maldive Islands, is the most important skipjack tuna fishing centre in the Indian Ocean (Jones and Kumaran, 1959). A review of the fishery is from Jones and Kumaran (1959). There is scarcely any difference between the Minicoy fishery and that operating in the Maldives (Jonklaas, 1967), and therefore the following description applies to the fisheries operating in both areas.

The skipjack tuna pole-and-line fishery of Minicoy, on which the economy of the island depends, is seasonal and extends from September to April with the bulk of the catch occurring in December–March. At the start of the skipjack tuna fishing season, the large fishing boats, which are kept covered onshore in the offseason, are launched. Constructed usually of coconut planks fastened by copper nails, they are about 12.5 m long and 3 m wide. There are three to four baitwells with two to three holes on the bottom of each to permit a free flow of water from below. Usually sails and oars are used to propel the craft.

A variety of small fishes found in the lagoon are used as baitfishes (Jones, 1958). The most common ones are pomacentrids, Daya jerdoni, Chromis caeruleus, and Pomacentrus spp. Other important baitfishes are the caesiodids, labrids, atherinids, and apogonids. They are caught with a liftnet. To attract them over the submerged net, crushed crabs and tuna entrails and flesh are scattered in the water. Attracted by the presence of food, the baitfishes gather and feed over the net, which is then quickly raised.

Usually 20–30 people constitute the crew. Fishing grounds are seldom more than 9 n mi (16 km) from the island. The captain is the bait chummer. During fishing 4 or 5 fishermen line up on each side of the vessel and flip the skipjack tuna on board. Fishing usually lasts 10–30 minutes and a fishing trip only 1 day. After the day's catch is unloaded, the skipjack tuna is processed by the womenfolk into smoked and cured fishsticks, locally called "mas min", and exported.

Hiebert and Alverson (1971) recognized several factors that limit extensive development of the Maldivian fisheries. Of primary importance is the availability of live bait (on some islands where it is unobtainable, pole and line are used with a plant lure). Also, because of difficulty in navigating from very deep to shallow water, the fishing vessels have only limited access to distant-water fishing grounds.

A small amount of skipjack tuna are also taken by trolling in the Indian Ocean. According to Jonklaas (1967), some skipjack tuna are taken by trolling gear in the Maldives. Sivasubramaniam (1965) reported that in Sri Lanka, in addition to pole and line, skipjack tuna are caught by troll gear and gillnet (Figure 7). A troll fishery for tuna also exists off the Tinnevelly coast in the Gulf of Mannar (Silas, 1967). However, in this troll fishery, the bulk of the catch consists of kawakawa, longtail tuna (Thunnus tonggol), yellowfin tuna, sailfish (Istiophorus platypterus), and seerfish (Scomberomorus commersoni). Skipjack tuna appeared only rarely in the catch.

In Sri Lanka, pole-and-line fishing has been practised since 1919 (Sivasubramaniam, 1965). Equipment and methods of operation are similar to those of fishermen in Minicoy and the Maldives, where this method has been in operation since 1909.

The live bait used in Sri Lanka is "red bait" (Dipterygonotus leucogrammicus), which congregates over large rocks at depths of 9-18 m. A special dipnet is used to catch the bait. An average day's catch of skipjack tuna and other tunas by a mechanized pole-and-line boat is usually about 0.2 t. Fishing is best off the southwest coast of Sri Lanka in November-March and off the east coast in July-September. Sivasubramaniam (1965) attributed large variations in annual landings of skipjack tuna in Sri Lanka to the annual variations in the spawning stock and availability of live bait.

Table 22 gives the production of skipjack tuna from the Indian Ocean for 1965-72 (FAO, 1973). It is obvious that skipjack tuna from the Maldive Islands predominated but it should be pointed out that production figures from the Maldives were estimated. Jonklaas (1967) stated that it was impossible to obtain any statistical data in such a vast and relatively underdeveloped archipelago. Not even reasonably accurate statistics of annual catches could be obtained, primarily because of the lack of communication and systematic recording of catch data by trained observers; but as a rule, Jonklaas estimated scombroid fishes, primarily skipjack tuna, constituted 90 percent of the fishes caught in the Maldives. Sivasubramaniam (1972) estimated that the Maldivian skipjack tuna fishery produced the largest percentage of the catch followed by the fishery based in Sri Lanka. The Minicoy fishery probably contributed about 1 000 t. Monthly data on fishing effort (days fished) and catches of skipjack tuna, yellowfin tuna, kawakawa, and frigate mackerel are given in Table 23 for 1965 for the fishery operating in the Maldive Islands.

Concerning fishery development in the Indian Ocean, the Japanese, as they have done in the southwestern Pacific, have taken the initiative in attempting to establish fishing bases. Cooperating with the Sri Lanka Government's programme to develop its fisheries, a Japanese firm sent two 250-GT pole-and-line fishing vessels to conduct exploratory skipjack tuna fishing (U.S. NMFS, 1973). The Japanese vessels started fishing in March 1973 in the Indian Ocean from a base at Galle in southwestern Sri Lanka (U.S. NMFS, 1973c). Exploratory fishing will be carried on for 1-1½ years under a permit granted by the Sri Lanka Government. Also, under the agreement, five or six natives and Government officials of Sri Lanka are scheduled to board each of the two Japanese vessels for training. If fishing, baitfish purchases, and labour costs are favourable, the Japanese firm hopes to organize a joint skipjack tuna fishing venture with interests in Sri Lanka.

In the Maldives, two Japanese firms have begun purchasing skipjack tuna (U.S. NMFS, 1972m). It was originally intended that purchases would be about 635 t per month but poor catches have reduced purchases to about 90 t per month. The Japanese firms negotiated a contract with the Maldivian Government to purchase skipjack tuna over the next 6 years.

4.2 Madagascar

Madagascar is an island in the Indian Ocean situated 240 n mi (445 km) off the east coast of Africa.

Fourmanoir (1957, 1960) and Gross (1967) stated that schools of skipjack and yellowfin tuna were frequently reported off the west and northwest coasts of Madagascar, particularly in January-April, i.e., during the warm seasons. Occurrence was reportedly very good even at other times of the year. Marcille (1972) confirmed that good concentrations of skipjack, sometimes associated with yellowfin tuna, are encountered off the northwestern shelf of Madagascar, around the various islands in the Mozambique Channel, as well as further north near the Providence and Amirantes Islands, and Seychelles Bank.

The Japanese started experimental skipjack tuna fishing off Madagascar in February 1972. A Japanese firm, after conducting a feasibility study at Seychelles Islands, has three 190-ton vessels working that area (U.S. NMFS, 1972, 1972e). At the same period, a French firm started exploratory skipjack tuna fishing in the same area. The performances achieved by the Japanese and French vessels are analysed by Marcille and Veillon (1972).

The Japanese pole-and-line boats (34 m, 200 t) concentrated their operations around Farquhar and Aldabra Islands in February-March and then in April-May moved progressively toward the Comoro Islands; from July-November most fishing took place off the northwest coast of Madagascar and in December-January between the islands of Aldabra and Providence; good occurrence of skipjack was also found in the vicinity of the Seychelles Islands where several visits were made at various periods of the year. The French survey arrived at similar conclusions regarding skipjack occurrence. It visited also the waters along the African shelf where little fish was found. In twelve months the three Japanese baitboats caught 4 003 t (3 768 of skipjack; 210 of yellowfin tuna); average daily catch per boat was 5.4 tons; seasonal variations in availability were limited to a slight decrease from July to October. Most of the schools were encountered in waters warmer than 27.5°C. Catches mainly consisted of two length groups (modes at 52 and 67 cm). In general, schools were small and highly mobile. From these observations, combined with the existence of clear waters and deep thermocline, it can be assumed that purse seining would be difficult. This assumption has been confirmed by experimental fishing conducted at a later stage by a French purse seiner (FAO, 1974).

Bait availability proved to be good. Japanese vessels used to catch the bait during the night in bays along the northwest coast of Madagascar at depths between 25 and 35 m. Main species caught were anchovy (Stolephorus indicus), jacks (Decapterus dayi and Selar crumenophthalmus), and sardine (Sardinella sirm). In average, 400-600 kg of fish attracted by light were caught by night with a blanket net. The French boat obtained slightly higher yield (500-700 kg/night) using a small purse seine. Bait resources are also abundant all the year round in the Seychelles Islands. Main species are Rastrelliger kanagurta and Coesio coerulaureus, available in bays.

Based on these fairly satisfactory results the Japanese firm decided to develop its activities. Five baitboats were scheduled to be in operation in April 1973 (Marcille and Veillon, 1973). The attention of other fishing firms, mainly Japanese and French, seeking joint ventures was also attracted. Two Japanese firms were scheduled to form a joint skipjack tuna fishing venture with local interest in November 1974 (U.S. NMFS, 1973d). In 1974, about 10 boats were operating and expected to land about 10 000 t (80-90 percent of skipjack) for that year (FAO, 1974).

TABLE 1. Annual catches (in metric tons) for various established fisheries for skipjack tuna in the Pacific Ocean

Year	Eastern Pacific[1]	Japan[2]	Hawaiian Islands[3]	Ryukyu Islands[4]	Philippine Island[5]
1900	-	-	191	-	-
1903	-	-	345	-	-
1917	190	82,795	-	-	-
1918	1,372	70,091	-	-	-
1919	3,128	64,395	-	-	-
1920	3,609	88,195	-	-	-
1921	517	81,592	-	6,702	-
1922	5,381	65,280	-	6,621	-
1923	5,200	67,784	-	6,423	-
1924	1,715	68,275	-	5,533	-
1925	6,457	69,536	-	4,854	-
1926	9,523	68,767	-	5,034	-
1927	15,335	85,701	-	3,890	-
1928	7,174	76,987	2,007	4,652	-
1929	12,246	72,135	1,514	3,288	-
1930	9,292	68,789	2,829	3,735	-
1931	7,488	80,343	2,777	2,594	-
1932	9,814	67,143	1,434	3,201	-
1933	7,569	77,305	2,522	3,110	-
1934	6,727	84,915	3,594	3,939	-
1935	7,801	72,881	2,210	3,288	-
1936	12,250	101,032	2,523	3,906	-
1937	21,366	105,907	5,800	3,194	-
1938	10,276	120,813	4,410	3,234	-
1939	13,663	100,518	3,903	3,304	-
1940	26,118	116,349	6,087	4,246	-
1941	11,692	91,629	1,656	4,194	-
1942	17,685	79,715	4	3,294	-
1943	13,349	51,691	-	2,318	-
1944	14,127	39,642	-	-	-
1945	15,438	19,653	1,772	-	-
1946	19,256	41,447	2,554	1,302	-
1947	24,259	48,732	2,536	2,945	-
1948	27,885	40,716	3,803	2,846	-
1949	36,749	46,471	4,488	3,419	-
1950	58,634	84,626	4,314	3,495	-
1951	54,948	104,309	5,863	2,606	-
1952	41,179	85,924	3,308	3,714	-
1953	60,626	72,690	5,470	2,620	-
1954	78,805	99,191	6,360	5,143	-
1955	58,061	99,626	4,397	3,235	-
1956	68,176	97,988	5,050	4,111	-
1957	58,197	97,418	2,781	4,056	-
1958	74,799	147,433	3,100	7,064	-
1959	80,559	166,707	5,631	10,957	-
1960	50,123	78,608	3,338	4,406	-
1961	64,910	144,327	4,942	5,922	-
1962	73,211	170,284	4,271	7,284	-
1963	93,033	112,887	3,674	5,514	-
1964	56,791	166,763	4,093	5,043	-
1965	84,324	136,067	7,329	3,800	-
1966	60,057	191,600	4,257	3,521	-
1967	122,381	154,200	3,647	5,136	500
1968	70,444	125,900	4,227	6,000	2,400
1969	58,605	138,800	2,705	3,400	600
1970	50,077	151,300	3,334	9,700	200
1971	103,330	99,100	6,051	21,700	700
1972	31,933	160,700	4,952	-	3,500
1973	42,457	201,000	4,875	-	2,500

[1] Data for 1917-66 are from Rothschild and Uchida (1968); data for 1967-73 are from Inter-American Tropical Tuna Commission (1974).

[2] Data for 1917-65 are from Rothschild and Uchida (1968); data for 1966-72 are from FAO (1973); figure for 1973 is from Kearney (p.4)

[3] Data for 1900-66 are from Rothschild and Uchida (1968); data for 1967-73 are from catch records of the Hawaii Division of Fish and Game.

[4] Data for 1921-67 are from Isa (1972); data for 1968-71 are from FAO (1972).

[5] Data for 1967-71 are from FAO (1972); data for 1972-73 are from Kearney (p.4).

TABLE 2. Annual catches (in metric tons) in newly developed or developing fisheries for skipjack tuna in the Pacific Ocean

Year	French Polynesia[1]	Indonesia[2]	New Hebrides[2]	Palau[3]	Papua New Guinea[4]	Solomon Islands[5]
1953	261	--	--	--	--	--
1954	324	--	--	--	--	--
1955	279	--	--	--	--	--
1956	371	--	--	--	--	--
1957	252	--	--	--	--	--
1958	181	--	--	--	--	--
1959	268	--	--	--	--	--
1960	320	--	--	--	--	--
1961	286	--	--	--	--	--
1962	385	--	--	--	--	--
1963	519	--	--	--	--	--
1964	401	--	2,900	--	--	--
1965	515	--	3,400	--	--	--
1966	731	--	5,700	2,942	--	--
1967	519	11,716	4,800	3,404	--	--
1968	--	12,907	6,700	5,212	--	--
1969	--	13,413	6,800	6,186	--	--
1970	--	13,642	6,800	8,441	2,430	--
1971	--	13,350	6,800	1,717	17,002	4,707
1972	--	13,317	6,800	[6]5,000	13,124	7,643
1973	--	[6]13,000	[6]6,800	[6]6,000	[6]28,000	6,500

[1] Data for 1953-55 are from Van Pel and Devambez (1957); data for 1956-67 are from Brun and Klawe (1968). Landings are for eviscerated fish. FAO (1972) estimates landings to be about 1,500 MT per year in 1965-71.

[2] Data are from Kearney (p. 4). Figures for New Hebrides may be higher than actual catches.

[3] Data are from Congress of Micronesia (1972). Catches for November-December 1971 not available at time of publication.

[4] Data for 1970-71 are from Kearney (1973); data for 1972-73 are from Kearney (1974); catches include small amounts of other tunas.

[5] Data for 1971-72 are from Kearney (personal communication); data for 1973 are from U.S. NMFS (1974).

[6] Estimated.

TABLE 3. Monthly landings of skipjack tuna, *Katsuwonus pelamis*, at the Papeete Market (in kg) (from Brun and Klawe, 1968)

Year	Month												Total
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	
1954		41,807	23,952	6,903	31,031	31,445	15,547	8,746	18,940	35,098	39,696	29,791	282,956
1955	34,000	37,567	34.835	32,449	51,564	19,538	11,311	3,467	6,294	5,286	9,059	33,492	278,862
1956	47,412	44,326	46,527	40,417	36,504	14,262	14,660	8,632	8,589	3,640	36,245	69,473	370,687
1957	50,408	35,684	32,357	22,495	29,149	21,120	7,788	5,185	4,364	13,689	12,901	17,228	252,368
1958	14,897	19,392	14,567	13,946	32,857	16,474	10,395	7,340	12,347	11,611	13,466	13,557	180,849
1959	14,050	14,020	9,889	16,956	36,729	36,274	19,737	13,339	8,512	22,973	22,953	52,093	267,525
1960	39,881	41,873	36,131	41,114	33,486	29,659	15,512	5,407	3,494	9,775	23,149	40,385	319,866
1961	41,419	35,034	32,480	29,370	33,145	22,161	10,579	9,228	8,423	16,290	18,822	29,064	286,015
1962	30,344	30,056	39,451	41,870	34,589	25,236	16,290	7,767	24,069	44,290	38,678	52,512	385,152
1963	78,223	41,742	40,993	45,540	61,327	40,677	26,361	21,789	23,711	27,747	48,314	62,917	519,341
1964	41,989	40,933	43,508	31,374	41,409	24,840	12,588	15,109	21,122	33,555	46,456	47,864	400,747
1965	38,183	34,535	32,410	41,479	62,915	57,759	26,103	28,443	23,831	42,572	49,126	77,892	515,248
1966	70,289	48.881	41,198	53,849	63,616	78,799	51,443	48,984	75,488	75,792	63,792	58,759	730,860
1967	51,926	79,328	56,603	44,950	62,654	35,198	13,903	6,030	12,091	41,105	46,033	69,172	518,993
1968	58,291												

TABLE 4. Monthly landings of yellowfin tuna, *Thunnus albacares*, at the Papeete Market (in kg) (from Brun and Klawe, 1968)

Year	Month												Total
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	
1954		11,468	7,206	8,474	10,398	9,514	3,465	1,913	2,631	3,846	9,913	6,491	75,319
1955	7,063	14,775	4,394	7,777	7,974	4,223	3,137	2,410	2,160	2,440	1,132	4,073	61,558
1956	12,303	7,269	8,907	2,425	2,368	1,754	1,285	867	112	654	1,170	1,454	40,568
1957	3,296	5,777	5,690	7,162	6,496	2,110	1,756	447	342	2,539	4,273	3,954	43,842
1958	8,959	23,987	13,392	4,409	7,706	5,273	2,389	1,877	1,172	1,009	2,588	5,724	78,485
1959	12,805	5,557	8,340	6,016	8,524	3,090	1,986	2,689	1,073	5,389	9,232	10,686	75,387
1960	2,886	1,371	12,395	6,208	7,352	7,820	4,382	3,545	1,063	1,055	1,780	9,948	59,805
1961	19,570	15,422	13,504	18,409	10,258	4,628	3,737	712	1,148	1,737	5,038	14,672	108,835
1962	16,756	20,010	12,132	10,090	13,525	8,051	5,243	2,792	664	1,840	8,788	26,273	126,164
1963	17,170	15,431	18,017	6,080	9,256	5,559	3,795	2,001	2,108	4,655	9,172	13,823	107,067
1964	10,551	8,232	11,389	11,830	11,590	7,040	4,751	3,695	2,017	1,504	5,073	9,906	87,578
1965	5,021	5,475	4,673	2,622	3,967	3,340	3,416	567	743	1,073	3,437	6,758	41,092
1966	7,987	7,933	3,841	2,873	8,478	4,551	2,950	1,828	1,961	2,689	5,820	7,366	58,277
1967	21,270	28,982	26,421	9,364	9,498	8,232	1,567	509	185	2,844	2,204	9,798	120,872
1968	13,180												

TABLE 5. Live-bait skipjack tuna fishery experiments in various French Polynesian Island groups (from Doumenge, 1973)

Boat	Period	Trips	Fish caught								Total		Yield/trip	
			Skipjack tuna						Yellowfin tuna					
			2-3 kg		3-8 kg		8-20 kg							
			No.	kg	No.	kg	No.	kg	No.	kg	No.	kg	No.	kg
Leeward Islands														
Moetu	20-25 Feb. 1972	2	27	54							27	54	13.5	27
	19-30 Mar. 1972	5	970	2,910					62	2,440	1,032	5,350	206.4	1,078
	1-7 July 1972	7	181	543					173	990	354	1,533	50.5	219
	21-24 Aug. 1972	2			270	4,050					270	4,050	135	2,025
	28 Aug.-8 Sept. 1972	4	162	426					3	90	165	516	41	129
Anela	14-20 Dec. 1972	4	635	3,810	396	3,168	37	555	46	257	1,114	7,790	2,785	1,947.5
	14-18 Jan. 1973	2	80	160			731	10,103	6	80	817	10,343	408.5	5,171.5
Tuamotu														
Moetu	24 July-3 Aug. 1972	4	79	237	2	16					81	253	20	55.5
Anela	3-7 Dec. 1972	3	246	663							246	663	82	221
Marquesas														
Anela	19 Feb.-25 Mar. 1973	5			1,735	10,410					1,735	10,410	347	2,082
	27 May-7 Apr. 1973	1	391	1,173	2,110	16,880					2,501	18,053	2,501	18,053

TABLE 6. Results of experimental live-bait fishery in the Windward Islands (from Doumenge, 1973)

Boat	Period	Trips	Fish caught								Total		Yield/trip	
			Skipjack tuna						Yellowfin tuna					
			2-3 kg		3-8 kg		8-20 kg							
			No.	kg	No.	kg	No.	kg	No.	kg	No.	kg	No.	kg
Moetu	15-18 Feb. 1972	1	32	64					24	48	56	112	56	112
	6-11 Mar. 1972	2	34	68			46	690	10	100	90	868	45	434
	13-18 Mar. 1972	1			1	8	127	1,918			128	1,926	128	1,926
	30 Mar.-2 Apr. 1972	1					80	1,200			80	1,200	80	1,200
	4-8 Apr. 1972	2	50	150					36	360	86	510	43	255
	10-13 Apr. 1972	3	108	216			2	30	100	1,200	210	1,446	70	482
	17-22 Apr. 1972	3	98	196	2	16			17	85	117	297	39	99
	25-29 Apr. 1972	2					15	180			15	180	7.5	90
	9-19 May 1972	5	229	458			87	870	70	420	386	1,748	77.2	349.6
	23-28 May 1972	4			13	91	42	425	2	82	57	598	20.5	149.5
	29 May-2 June 1972	2	22	44					19	95	41	139	20.5	69.5
	5-10 June 1972	2	—	—	87	435	—	—	—	—	87	435	43.5	217.5
	Total	28	573	1,196	103	550	399	5,313	278	2,390	1,353	9,449	48.5	337.5
Anela	10-13 Dec. 1972	3	907	2,721	204	1,020	121	1,573	79	237	1,311	5,551	437	1,850
	7-11 Jan. 1973	3	72	37			853	11,089			925	11,126	308.3	3,708.6
	12 Jan. 1973	1			253	3,102					253	3,102	253	3,102
	25-26 Jan. 1973	2					500	8,068			500	8,068	250	4,034
	28-30 Jan. 1973	2					1,606	21,722			1,606	21,722	803	10,861
	31 Jan.-2 Feb. 1973	2	20	40			982	12,766	2	4	1,004	12,810	502	6,405
	4-7 Feb. 1973	3					1,300	16,900			1,300	16,900	433.3	5,633.3
	8-9 Feb. 1973	1					311	4,043			311	4,043	311	4,043
	10-15 Feb. 1973	2	—	—	—	—	1,418	18,434	—	—	1,418	18,434	709	9,217
	Total	19	999	2,798	457	4,122	7,091	94,595	81	241	8,628	101,756	449	5,355.5
Redondo	27 Mar.-7 Apr. 1973	5	161	644			50	750	1,200	3,600	1,411	4,994	282.2	998.8
	Grand total	52	1,733	6,638	560	4,672	7,540	100,658	1,559	6,231	13,392	116,199		

TABLE 7. The species and amount of baitfish caught day and night baiting in Pago Pago Harbor and Apia Harbor by the RV *Charles H. Gilbert* (from Hida, 1970)

Baiting locality	Time of day	Sets	Amount of bait caught	Species
		Number	Buckets	
Pago Pago Harbor	Night	8	54	Mackerel, *Rastrelliger kanagurta*
			22	Sardines, *Sardinella melaneura* and *Herklotsichthys punctatus*
			4	Bigeye scad, *Trachurops crumenophthalmus*
	Day	31	88	Sardines, *S. melaneura* and *H. punctatus*
Apia Harbor	Day	5	13	Silverside, *Pranesus pinguis*

TABLE 8. Baiting effort (sets), total catch by species and all species combined, and catch per set at night baiting stations at American Samoa, August 1970-June 1973

Month-year	No. of sets	Total catch	Catch per set	*Stolephorus* sp. Amount caught		*Sardinella* spp. Amount caught		*Herklotsichthys punctatus* Amount caught		Others Amount caught	
	No.	Bkt.	Bkt.	Bkt.	Percent	Bkt.	Percent	Bkt.	Percent	Bkt.	Percent
Aug.-Dec. 1970	67	202	3.0	90	44.6	32	15.8	64	31.7	16	7.9
Jan.-Dec. 1971	133	337	2.5	72	21.4	43	12.8	68	20.2	154	45.7
Jan.-Dec. 1972	49	149	3.0	23	15.4	3	2.0	31	20.8	92	61.7
Jan.-Jun. 1973	58	119	2.0	7	5.9	76	63.9	23	19.3	13	10.9

Data for August 1970-June 1972 are from Swerdloff (1974); data for July 1972-June 1973 are from Sesepasara (1973).

TABLE 9. Noon positions, dates and number and kinds of schools sighted around the Samoa Islands during cruise 117 of the RV *Charles H. Gilbert* (from Hida, 1970)

Noon Position		Date	Number of Schools Sighted[1]						
Lat. (S.)	Long. (W.)	1970	SJ	YF	KK	Mixed YF, SJ	UN	Mixed KK, DO, SK	Total
12°00'	169°15'	2/8	-	-	-	-	4	-	4
South of Pago Pago		2/11	-	-	-	-	5	-	5
16°55'	170°45'	2/12	2	1	-	-	4	-	7
16°03'	170°13'	2/13	4	-	-	-	2	-	6
14°33'	170°23'	2/15	2	-	-	-	2	-	4
14°30'	169°22'	2/16	-	1	-	1	3	-	5
13°37'	169°24'	2/17	-	-	-	-	1	-	1
14°09'	171°00'	2/23	-	-	1	-	2	-	3
14°27'	171°45'	2/25	1	-	-	-	-	-	1
13°49'	173°15'	2/26	-	3	-	2	4	-	9
13°50'	172°08'	2/27	-	-	2	-	3	-	5
14°12'	172°12'	3/1	1	1	1	1	1	-	5
14°45'	171°02'	3/2	1	-	-	-	5	-	6
14°19'	170°36'	3/5	-	-	-	-	3	-	3
14°18'	170°35'	3/6	-	-	-	-	4	-	4
14°19'	170°39'	3/10	-	-	1	-	1	-	2
14°17'	170°53'	3/11	-	-	1	-	-	1	2
14°51'	170°30'	3/14	2	-	-	-	1	-	3
14°11'	170°14'	3/18	-	2	-	-	4	-	6
14°02'	169°22'	3/19	-	-	-	2	4	-	6
14°39'	168°36'	3/20	4	-	-	1	2	-	7
14°38'	170°14'	3/21	3	-	-	-	5	-	8
14°25'	170°47'	3/23	3	-	-	-	4	-	7
15°42'	170°45'	3/24	-	-	-	-	2	-	2
14°23'	170°35'	3/25	-	-	-	-	1	-	1
14°15'	170°56'	3/26	2	1	1	1	4	-	9
13°46'	171°45'	3/27	-	-	-	-	2	-	2
13°42'	173°08'	3/28	1	1	-	-	3	-	5
14°15'	172°29'	3/29	-	-	1	-	5	-	6
13°44'	171°50'	3/31	-	-	2	2	1	-	5
15°03'	171°16'	4/1	2	1	-	-	2	-	5
Total			28	11	10	10	84	1	144

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[1] SJ = skipjack; YF = yellowfin; KK = kawakawa; UN = unidentified; DO = dolphin; SK = shark.

TABLE 10. Information on large tuna schools seen in the vicinity of the Samoa Islands during cruise 117 of the RV *Charles H. Gilbert* (from Hida, 1970)

Position		Date	Species	Fish Size	Type of
Lat. (S)	Long. (W)	1970	Common names of tuna	pounds	school[1]
14°30'	169°21'	2/16	Yellowfin	20-50	Boiler
13°25'	172°45'	2/26	Yellowfin	30-40	Boiler
14°09'	172°11'	3/1	Yellowfin-Skipjack	7-16	Boiler
14°12'	169°35'	3/19	Yellowfin-Skipjack	5	Breezer
13°30'	168°41'	3/19	Skipjack Yellowfin	11 60	Breezer
14°39'	168°25'	3/20	Skipjack	10	Boiler
14°37'	168°25'	3/20	Skipjack	10	Boiler
14°45'	168°51'	3/20	Skipjack	6	Boiler
14°26'	170°42'	3/23	Skipjack	8	Breezer
14°27'	170°46'	3/23	Skipjack	7-8	Breezer
13°54'	171°21'	3/26	Skipjack	5	Breezer
14°12'	172°04'	3/31	Skipjack Yellowfin	6 9	Jumper

[1] See Scott (1969)for school terminology.

TABLE 11. Catches of skipjack tuna and other tunas caught in Australian waters, 1960-61 to 1971-72

Fiscal year	Catch (MT)	
	Tuna[1]	Skipjack tuna
1960-61	4,429	--
1961-62	4,814	--
1962-63	4,989	48
1963-64	8,134	34
1964-65	7,184	2
1965-66	8,054	1
1966-67	5,649	2
1967-68	6,792	4
1968-69	8,916	35
1969-70	8,450	1
1970-71	6,802	42[2]
1971-72	10,125	105[2]

[1] Catches from 1960-61 to 1969-70 include catches of skipjack tuna not reported separately by several states.

[2] Catches of skipjack tuna in 1970-71 and 1971-72 are reported separately from other tunas.

TABLE 12. Number and percentages of schools, by species, sighted in Fijian waters in 1972

Species	Schools sighted	
	Number	Percent
Skipjack tuna	247	37.8
Yellowfin tuna	53	8.1
Skipjack-yellowfin mixed	44	6.7
Kawakawa	40	6.1
Skipjack-kawakawa mixed	8	1.2
Tuna-pelagic species mixed	28	4.3
Mahimahi (*Coryphaena hippurus*)	18	2.8
Miscellaneous species	18	2.8
Unidentified	197	30.2
Total sightings	653	

TABLE 13. Summary of joint-venture operations in Indonesia

Month and year	Area of operation	Size of fleet	Remarks
Nov. 1969 to Mar. 1971[1]	Sorong, West Irian.	Five 110-ton catcher vessels, four 10-ton bait catchers, and one 700-ton freezer mother ship.	Results of fishing not satisfactory.
Apr.-Sept. 1971[2]	In Molucca Sea off Halmahera Island; vessels based in Ternate.	Five 110-ton catcher vessels two 400-ton carriers.	Joint venture, called East Indonesian Fisheries Company formed. Plans call for fleet of 10 vessels. Catch target for first year is 4,000 MT. Vessel crew half Japanese and half Indonesian at present; to be all Indonesian in future.
Aug. 1971[3]	Butung Island in Banda Sea.	Three catcher vessels and one mother ship.	No information on results of survey.
Sept. 1971[4]	Pandiang, Sumatra Island with fishing in Sunda Strait.	Three or four catcher vessels.	Operations terminated in March 1972; probably because of poor fishing.
Sept. 1971[5]	Kendari, Celebes Island.	Five 39-ton catcher vessels and one 1,000-ton mother ship.	Joint venture formed. Landings reached 600 tons. Catch was 2-3 tons per vessel per day. Bait available in sufficient amounts.
Dec. 1971 to July 1972[1]	West coast of Sumatra Island in the Indian Ocean.	One 190-ton catcher vessel.	Survey terminated after a few months because of difficulty in obtaining sufficient quantities of live bait and because of poor weather conditions.
May 1972 to Dec. 1972[1]	Kotobaru on Laut Island; test fishing in Makassar Strait and in Flores Sea.	One 190-ton catcher vessel.	Results were disappointing, but conclusion was that a brief test fishing by a single vessel was inadequate.

Source of information:

[1] Katsuo-Maguro Nenkan, 1973
[2] U.S. NMFS, 1971, 1971*b*, 1971*i*, 1972*f*
[3] U.S. NMFS, 1971*e*
[4] U.S. NMFS, 1971*f*, 1972*b*
[5] U.S. NMFS, 1972*b*, 1972*d*

TABLE 14. Summary of joint-venture operations in Papua New Guinea (from Pownall, 1972)

Joint venture base location	Fleet	Area of operation	Future plans
Kavieng on northern tip of New Ireland; also a tuna smoke-drying plant on Nago Island	Operates two mother ships (1,000 and 500 GT), a 150-ton Japanese steel catcher boat with automatic fishing poles, and nine chartered Okinawan 39-ton, wood, pole-and-line fishing boats.	Bismarck Sea	[No information]
Rabaul in New Britain	Operates two mother ships and nine chartered Okinawan catcher boats.	Bismarck Sea	Hopes to increase fleet to 3 mother ships and 15 catcher boats; expects to catch 15,000 tons of skipjack tuna per year; plans to build a cold storage and a smoking plant. Within 5 years, they expect to be operating five boats under Papua New Guinea flag. Fishery training expected for 500 Papua New Guinean fishermen.
Madang	Operates two mother ships (1,000 tons), eight chartered Okinawan, and one 192-ton Japanese catcher boats.	[No information]	Catches were disappointing; all vessels in fleet except one large Japanese catcher boat returned to Japan.
Still on survey	Operates one mother ship; three chartered Okinawan catcher boats, and the 400-ton pole-and-line vessel, *Redondo*.	Bismarck Sea	[No information]

TABLE 15. Distribution by area of the total catch and average weight of skipjack tuna in 1971 (from Kearney, 1973)

1971	Northeastern Bismarck Sea		Eastern Bismarck Sea		Southwestern Bismarck Sea	
	Total catch	Average weight of skipjack tuna	Total catch	Average weight of skipjack tuna	Total catch	Average weight of skipjack tuna
	Tons	Kg	Tons	Kg	Tons	Kg
January	447.6	3.9	470.1	-	0	-
February	625.3	3.8	366.6	-	0	-
March	477.3	3.9	569.4	-	414.9	5.0
April	367.8	3.8	645.8	-	498.1	4.8
May	649.4	3.7	788.4	4.0	446.7	4.7
June	224.3	3.3	1078.9	-	736.3	5.1
July	87.7	3.5	1348.3	4.2	516.5	4.9
August	353.3	3.3	1257.0	3.9	416.5	4.9
September	534.9	3.4	818.9	3.8	135.8	4.7
October	538.1	3.8	520.2	4.6	16.3	5.0
November	412.8	3.40	462.7	4.2	86.9	3.6
December	129.5	3.2	381.6	4.0	188.5	4.5
Total	4,837.1		8,707.9		3,456.5	
Grand total					17,002.5	

TABLE 16. Monthly catches of skipjack, yellowfin, and other tunas in the Papua New Guinea skipjack tuna fishery, 1970-71 (from Kearney, 1973)

Year	Month	Catch (metric ton)				Average catch/day
		Skipjack	Yellowfin	Others	Total	
1970	Jan.	-	-	-	-	-
	Feb.	-	-	-	-	-
	Mar.	279.2	27.8	0.0	307.0	3.743
	Apr.	336.6	11.3	0.1	348.0	4.704
	May	361.8	8.2	0.1	370.1	4.512
	June	438.5	2.5	0.0	441.0	5.444
	July	472.8	7.5	0.0	480.3	6.403
	Aug.	101.4	11.3	0.0	112.7	4.026
	Sept.	-	-	-	-	-
	Oct.	-	-	-	-	-
	Nov.	143.9	0.3	1.0	145.2	4.539
	Dec.	220.3	5.4	0.5	226.2	3.968
Totals:		2,354.5	74.3	1.7	2,430.5	
1971	Jan.	899.7	16.7	1.3	917.7	3.543
	Feb.	969.8	21.3	0.8	991.9	3.493
	Mar.	1,445.0	13.8	0.8	1,461.6	4.402
	Apr.	1,499.1	6.4	6.1	1,511.6	4.270
	May	1,862.2	15.1	7.1	1,884.4	5.510
	June	2,037.9	1.3	0.4	2,039.6	6.433
	July	1,950.6	0.8	1.1	1,952.5	5.515
	Aug.	2,021.9	3.0	1.9	2,026.8	4.231
	Sept.	1,486.0	3.0	0.6	1,489.6	3.547
	Oct.	1,058.3	2.7	2.6	1,064.6	3.775
	Nov.	945.6	15.6	1.3	962.5	2.856
	Dec.	687.6	8.3	3.7	699.6	2.332
Totals:		16,863.7	108.0	27.7	17,002.4	

TABLE 17. Skipjack tuna baitfish used in the Ryukyu Islands (asterisks denote important species) (from Isa, 1972)[1]

Family	Species	Japanese name	Local name
Clupeidae	*Sardinella clupeoides*	Yamato-mizun	Yamato-mizun
	Sardinella sindensis	Miyako-iwashi	Mizun
	Harengula ovalis	Mizun	Mizun or ashichin
Dorosomatidae	*Konosirus punctatus*	Konoshiro	Ashichin
Dussumieridae	**Spratelloides japonicus*	Kibinago	Sururu
	**Spratelloides delicatulus*	Minami-kibinago	Shiiraa
	Spratelloides atrofasciatus	Bakajako	Bakajako
Engraulidae	*Stolephorus indicus*	Indo-ainoko	Mizusururu
	Stolephorus zollingeri	Taiwan-ainoko	Mizusururu
	**Stolephorus pseudoheterolobus*	Mizusururu	Mizusururu
Atherinidae	*Allanetta woodwardi*	Okinawa-toogoroo	Hadaraa
Carangidae	*Decapterus macrosoma*	Kusayamoro	Nagaiyuu
	**Trachurops crumenophthalmus*	Meaji	Gatsun
Apogonidae	**Archamia fucata*	?	Ufumii
	Apogon notatus	Kurohoshi-ishimochi	Ufumii
Pempheridae	*Parapriacanthus beryciformis*	Kinmemodoki	Gasagasaa
Caesionidae	**Caesio tile*	Kumasasa-hanamuro	Ukuu
	**Caesio chrysozonus*	Takasago	Saneeraa
Pomacentridae	**Chromis ternatensis*	Kaburaya-suzumedai	Hikaagwaa
	Chromis caeruleus	Debasuzumedai	Hikaagwaa
	Abudefduf dickii	Ishigaki-suzumedai	Hikaagwaa

[1] Source: Mr. Nishijima, University of Ryukyu Islands, pers. comm.

TABLE 18. Baitfish used, in metric tons, in the three major localities in the Ryukyu Islands skipjack tuna fishery, 1966 and 1967 (from Isa, 1972)

Baitfish family	Yaeyama		Miyako		Okinawa		Total	
	1966	1967	1966	1967	1966	1967	1966	1967
Apogonidae	34.9	77.5	7.7	10.5	29.5	23.1	71.7	111.1
Caesionidae	16.7	35.4	20.5	1.2	29.9	15.7	67.1	52.3
Dussumieridae	3.3	3.2	6.0	22.7	45.4	19.1	54.7	45.0
Engraulidae	1.5	-	2.1	17.2	15.3	8.2	18.9	25.4
Carangidae	0.4	-	0.9	-	40.1	17.7	41.4	17.7
Clupeidae	0.5	-	-	-	7.3	5.0	7.8	4.8
Pomacentridae	4.0	5.6	0.1	-	-	0.5	4.1	6.1
Dorosomatidae	-	-	-	-	1.0	6.8	1.0	6.8
Others	7.5	-	-	-	-	-	7.5	-
Total	68.8	121.7	37.3	51.6	168.1	96.1	274.2	269.4

TABLE 19. Monthly landings (in metric tons) of skipjack tuna in the Ryukyu Islands, 1959, 1962-63, and 1965-67 (from Isa, 1972)

Month	1959	1962	1963	1965	1966	1967	Monthly average	Per-cent
January	20.4	6.2	5.5	15.5	23.5	72.1	23.9	0.4
February	21.0	7.1	2.3	15.1	30.1	86.3	26.9	0.4
March	14.5	11.8	3.2	11.8	28.8	23.3	15.6	0.2
April	99.0	89.6	118.0	62.1	128.7	33.6	88.5	1.4
May	643.3	602.0	581.3	469.8	283.1	241.0	470.1	7.6
June	1,766.8	1,518.7	843.9	420.9	466.7	788.6	967.6	15.6
July	3,594.4	2,127.8	1,584.4	1,164.7	1,145.4	1,342.9	1,826.6	29.5
August	2,742.9	1,671.9	1,424.2	933.6	1,011.1	1,397.5	1,530.2	24.7
September	1,650.8	1,017.6	678.9	419.2	200.8	967.6	822.5	13.3
October	1,223.8	139.9	175.0	135.4	179.1	152.8	334.3	5.4
November	69.3	26.2	53.0	68.7	16.7	14.2	41.4	0.7
December	111.5	1.4	43.5	62.4	7.4	15.6	40.3	0.6
Total	11,957.7	7,220.2	5,513.2	3,779.2	3,521.4	5,135.5	6,187.9	100.0

Source: GRI Annual Fisheries Reports for 1959, 1962-63 and 1965-67.

TABLE 20. Skipjack tuna catch in metric tons landed in the former Japanese mandated islands, 1922-41 (from Smith, 1947; Shapiro, 1948)

	Saipan	Yap	Palau	Truk	Ponape	Jaluit
1922	2	-	-	4	4	-
1923	3	1	-	3	-	-
1924	9	2	2	5	<1	-
1925	15	2	9	6	5	-
1926	45	2	42	3	<1	-
1927	28	<1	15	8	2	<1
1928	26	1	131	5	<1	-
1929	25	<1	229	215	<1	-
1930	258	<1	157	913	6	-
1931	564	<1	548	1,097	525	81
1932	1,310	-	1,592	810	534	615
1933	1,762	-	2,144	1,883	927	172
1934	2,516	4	3,779	1,200	1,202	255
1935	1,786	-	5,391	3,002	1,313	230
1936	1,696	-	3,836	5,870	2,696	168
1937	2,697	-	13,775	12,434	4,064	91
1938	2,392	149	3,420	5,295	1,496	7
1939	2,087	36	3,549	7,640	3,708	-
1940	3,379	4	6,047	7,217	1,586	<1
1941	1,295	5	3,301	4,337	2,419	169

TABLE 21. Number of boats fishing, catches of skipjack tuna, and catch per boat, by month, in the Palau skipjack tuna fishery, 1966-71 (from Congress of Micronesia, 1972)

Month	1966			1967			1968		
	Boats	Catch	Catch per boat	Boats	Catch	Catch per boat	Boats	Catch	Catch per boat
	No.	MT	MT	No.	MT	MT	No.	MT	MT
January	—	101.414	—	5	361.103	72.2	10	341.896	34.2
February	—	220.402	—	4	107.918	26.9	9	477.397	53.0
March	—	133.402	—	4	101.678	25.4	8	443.479	55.4
April	—	108.210	—	4	120.516	30.1	6	375.414	62.5
May	—	161.820	—	4	130.399	32.6	6	733.787	122.3
June	—	185.283	—	10	258.949	25.9	11	771.853	70.1
July	—	524.830	—	10	384.659	38.4	11	996.055	90.5
August	—	326.672	—	9	430.843	47.9	9	769.427	85.4
September	—	477.440	—	10	210.327	21.0	9	177.879	19.7
October	8	320.839	40.1	10	205.587	20.6	5	37.497	7.5
November	8	250.227	31.2	10	580.735	58.1	6	84.864	14.1
December	8	130.871	16.3	9	510.787	56.7	4	2.868	0.7
Total	—	2,941.600	—	—	3,403.501	—	—	5,212.416	—
Average	—	245.134	—	7.4	283.625	38.2	7.8	434.368	55.5
		1969			1970			1971	
January	8	72.107	9.0	7	389.421	55.7	6	242.875	40.4
February	9	141.385	15.8	7	274.983	39.2	6	102.734	17.1
March	8	35.330	4.4	6	192.730	32.1	8	199.799	24.9
April	5	58.195	11.6	7	422.949	60.4	7	190.919	27.2
May	5	259.846	51.9	9	1,021.297	113.5	8	466.544	58.3
June	4	623.630	155.9	9	1,642.223	182.4	8	282.685	35.3
July	8	678.585	84.8	9	2,343.803	260.4	12	72.200	6.0
August	9	1,282.252	142.4	9	1,055.522	117.3	12	78.200	6.6
September	9	809.540	89.9	2	95.873	47.9	12	197.877	16.5
October	9	593.678	65.9	5	149.753	29.5	6	31.895	5.3
November	7	702.714	100.4	5	512.560	102.5	—[1]	—	—
December	7	929.011	132.7	6	340.172	56.7	—[1]	—	—
Total	—	6,186.183	—	—	8,441.286	—	—	1,716.832	—
Average	7.3	515.515	70.3	6.75	703.441	104.2	8.5	171.683	20.2

[1] Data unavailable at time of publication.

TABLE 22. Catches of skipjack tuna in the Indian ocean, 1965-72

Year	Maldive Islands (1,000 MT)	Japan (1,000 MT)	Australia (1,000 MT)
1965	13.1[1]	0.1	--
1966	15.9[1]	0.1	--
1967	17.9[1]	0.2	--
1968	16.3[1]	0.3	--
1969	18.4	0.3	--
1970	20.0[1]	0.1	--
1971	28.9	0.1	0.0
1972	15.0[1]	0.1	0.1

[1] Data estimated or calculated by FAO.

TABLE 23. Catch of tuna (in thousands of fish) and fishing days by month and type of boat in the Maldive Islands, 1965. (a) Skipjack and yellowfin tunas; (b) Large skipjack tuna; (c) Kawakawa and frigate mackerel (from Hiebert and Alverson, 1971)

	Large boat (live-bait fishing)				Small boat (mailing trolling)			
	Days** fishing	(a)	(b)	(c)	Days** fishing	(a)	(b)	(c)
January	18,908	1,156	66	1,083	11,915	49	3	72
February	16,949	933	21	492	12,232	28	1	91
March	15,341	715	3	291	9,262	20	1	32
April	13,322	464	6	166	10,062	14	*	29
May	11,301	553	10	92	11,585	32	1	32
June	14,145	616	4	126	11,994	58	1	51
July	15,067	460	13	74	11,870	22	2	29
August	13,184	452	21	114	10,408	53	2	32
September	11,664	274	40	84	10,190	15	*	25
October	14,444	364	62	294	10,568	22	5	42
November	15,730	333	47	347	10,412	36	1	32
December	17,295	597	76	125	13,667	69	4	50
Total	177,350	6,917	369	3,288	134,165	418	21	517

* less than 500.

** minor discrepancies are due to rounding.

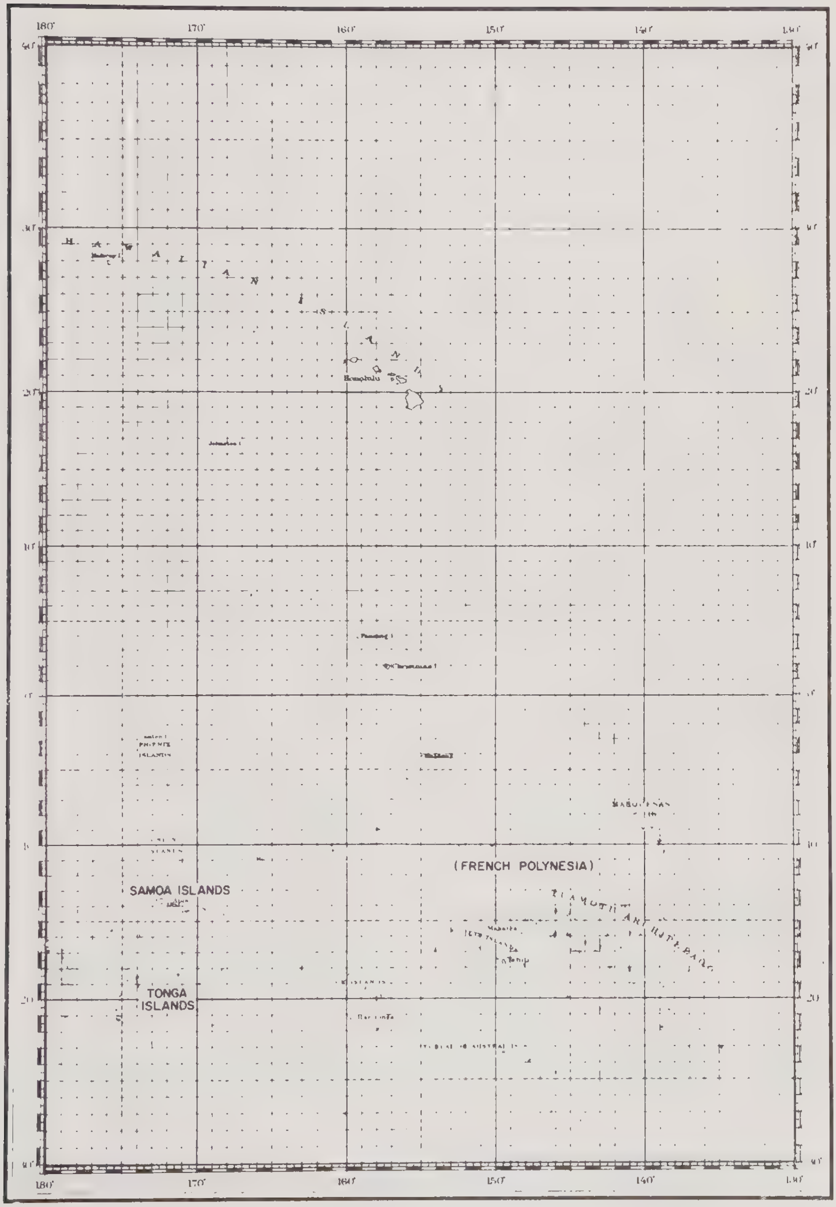

180°
170°
160°
150°
140°
130°
H A W A I I A N I S L A N D S
Honolulu
(FRENCH POLYNESIA)
SAMOA ISLANDS
TONGA ISLANDS

Figure 1. Island groups in the central Pacific Ocean.

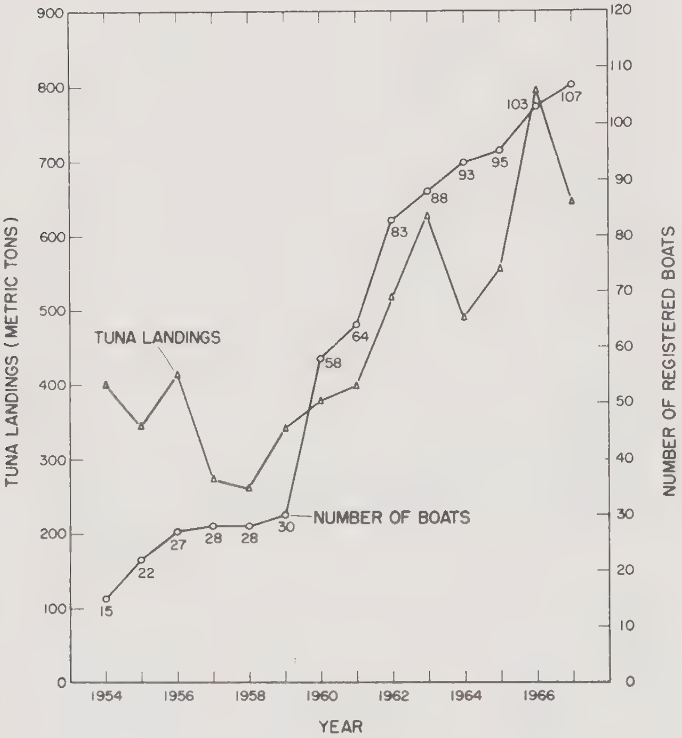


Figure 2. **French Polynesia**

Combined landings of skipjack and yellowfin tunas, and numbers of boats engaged in the tuna fishery (from Brun and Klawe, 1968).

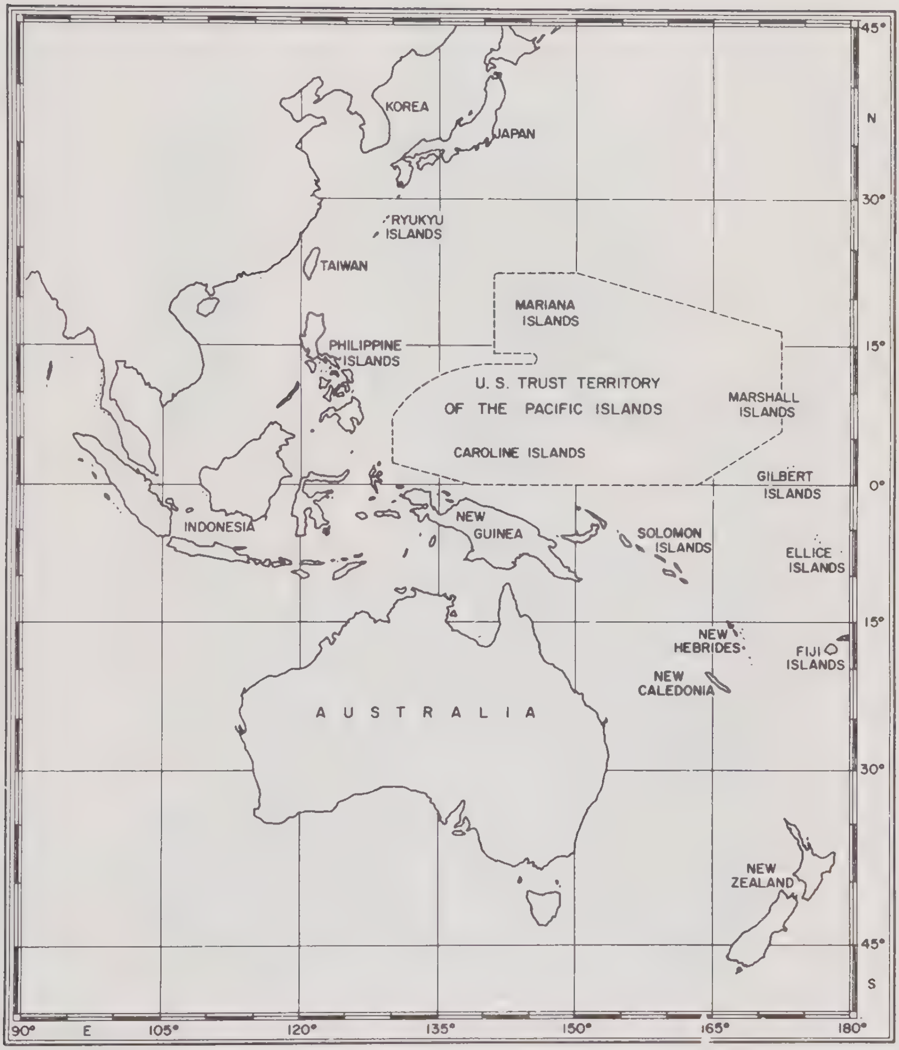

KOREA
JAPAN
RYUKYU ISLANDS
TAIWAN
MARIANA ISLANDS
PHILIPPINE ISLANDS
U. S. TRUST TERRITORY OF THE PACIFIC ISLANDS
MARSHALL ISLANDS
CAROLINE ISLANDS
GILBERT ISLANDS
INDONESIA
NEW GUINEA
SOLOMON ISLANDS
ELLICE ISLANDS
NEW HEBRIDES
FIJI ISLANDS
NEW CALEDONIA
AUSTRALIA
NEW ZEALAND
45°
N
30°
15°
0°
15°
30°
45°
S
90°
E
105°
120°
135°
150°
165°
180°

Figure 3. Island groups and countries in the western Pacific Ocean.

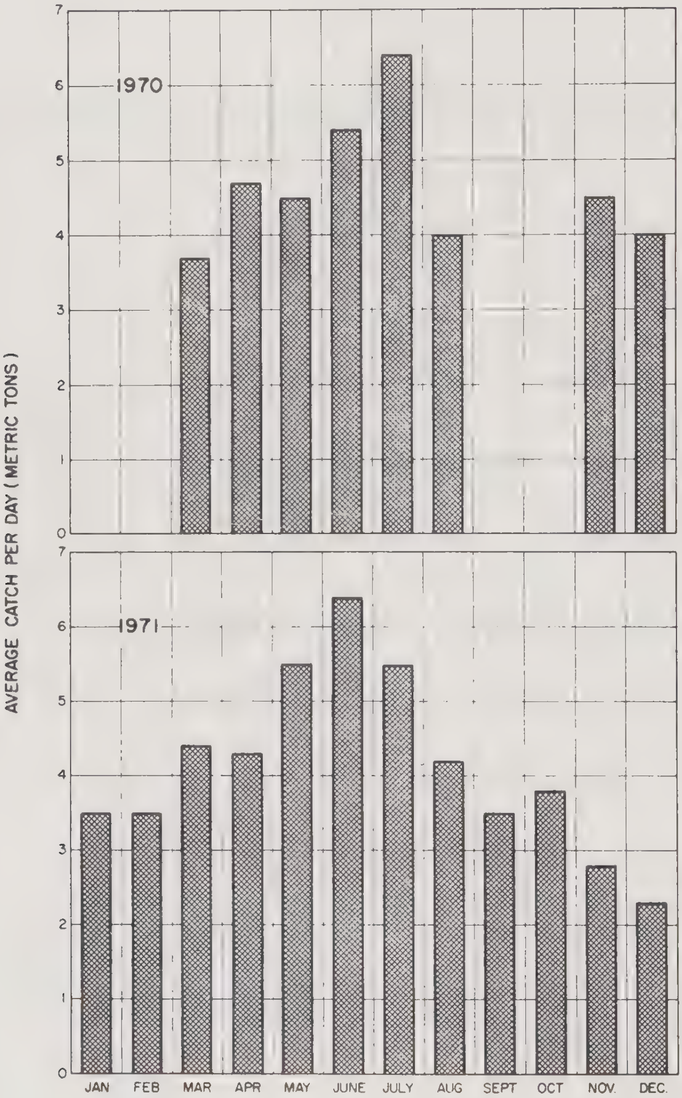
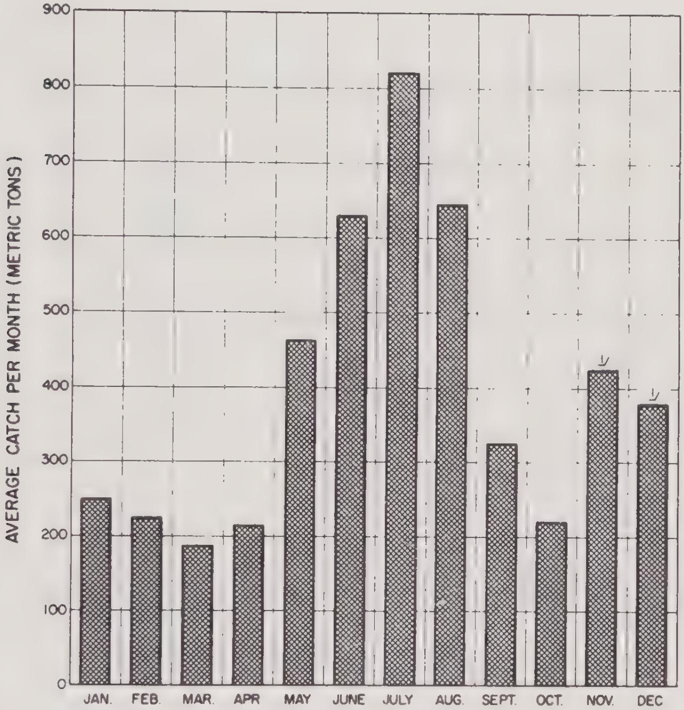
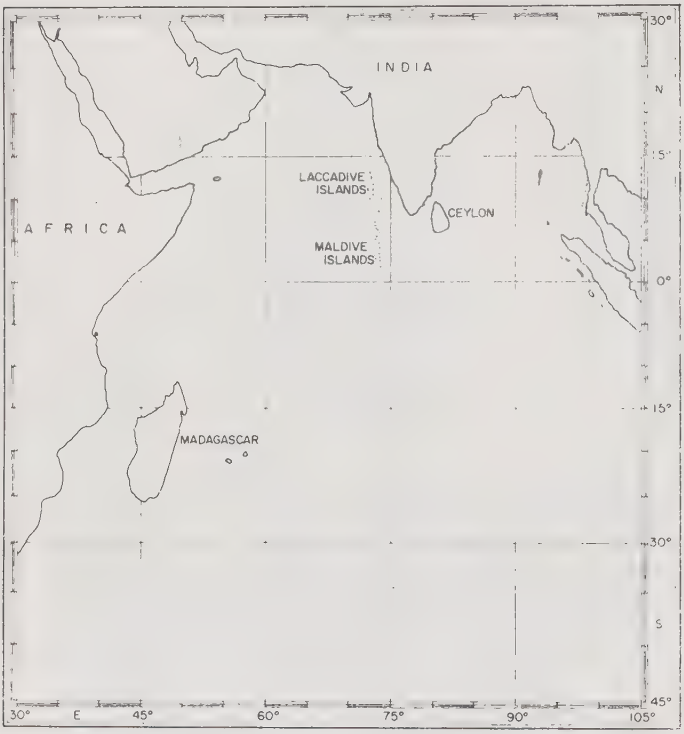


Figure 4. The average catch per day, by month, in the Papua New Guinea fishery, 1970-71.



[1] Based on data for 1966-70.

Figure 5. Average monthly catch of skipjack tuna in the Palau fishery, 1966-71.


INDIA
N
5°
LACCADIVE ISLANDS
CEYLON
AFRICA
MALDIVE ISLANDS
0°
15°
MADAGASCAR
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S
45°
30°
E
45°
60°
75°
90°
105°

Figure 6. Island groups within and bordering the Indian Ocean.

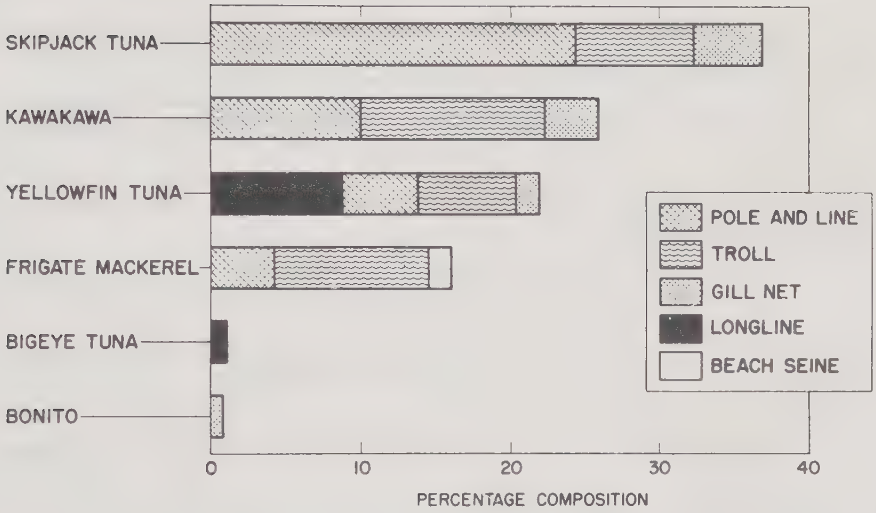

Figure 7. Sri Lanka

Percentage composition of tuna species caught from the coastal waters (from Sivasubramaniam, 1965).

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1973c Ocean. Foreign Fish.Inf.Release, (73-7):2

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7532

Synopsis of Biological Data on Striped Marlin, *Tetrapturus audax* (Philippi), 1887

SHOJI UEYANAGI[1] and PAUL G. WARES[2]

1 IDENTITY

1.1 Nomenclature

1.11 Valid Name

Tetrapturus audax (Philippi), 1887 is the name adopted by the most recent review of the family (Nakamura, Iwai, and Matsubara, 1968). The original combination was *Histiophorus audax* Philippi, 1887. Anal. Univ. Chile 71:34-39.

1.12 Objective synonymy

All synonyms are assumed to be subjective without consulting original papers and are listed under section 1.21.

1.2 Taxonomy

1.21 Affinities

Suprageneric

- Phylum Chordata
  - Subphylum Vertebrata
    - Superclass Gnathostomata
      - Class Osteichthyes
        - Subclass Actinopterygii
          - Order Perciformes
            - Suborder Xiphioidei
              - Family Istiophoridae

Generic

Genus *Tetrapturus* Rafinesque, 1810.

Caratteri di alcuni nuovi generi e nuove specie di animali [principalmente di pesci] e piante della Sicilia, con varie osservazioni sopra i medisimi. Palermo, 105 p.

Type-species *Tetrapturus belone* Rafinesque, 1810.

Robins and de Sylva (1960, 1963) placed the striped marlin in *Tetrapturus*, following the works of hierarchical classification of the family by Hirasaka and Nakamura (1947) and Nakamura (1949). This placement of *audax* in *Tetrapturus* is supported by Ueyanagi (1963b), Howard and Ueyanagi (1965), and Nakamura et al. (1968).

We follow the generic concept of Nakamura et al. (1968), who described the genus as follows:

> The height of the dorsal fin is greater than the body depth. The ventral fin rays are rather long, the fin membrane not well developed. The body is compressed (flat) and except for the striped marlin (Makajiki) and the white marlin (Nishimakajiki), extends in a straight line from the pre-occular area to the base of the dorsal fin. The cranium is long and narrow. The neural and haemal spines of the central vertebrae form a parallelogram. There are 24 vertebrae (12 + 12 = 24). The lateral appophysis[3] is not well developed.

These authors include the following species in the genus: *T. angustirostris* Tanaka, 1914; *T. belone* Rafinesque, 1810; *T. pfluegeri* Robins and de Sylva, 1963; *T. albidus* Poey, 1861; *T. audax* (Philippi, 1887).

Specific

Identity of type specimen:

Species *T. audax* (Philippi, 1887).

Type specimen: Apparently one of the two deposited in the Museo Nacional de Historia Natural, Santiago, Chile by Rudolfo A. Philippi.

Type Locality: Iquique, Chile.

Diagnosis: Ventral fins and two caudal keels are present; snout cross section is nearly circular; first dorsal fin anteriorly is about same height as body depth or greater[4] and is not saillike but slopes abruptly

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[3] See Ueyanagi and Watanabe (1965) for usage of this term.

[4] Due to allometric growth of the dorsal fin relative to body depth the fin height may be less than body depth in fish larger than 360 cm FL (Royce, 1957).

posteriorly, the middle rays being much shorter than the anterior; snout is fairly long; vent is located very close in front of first anal fin; pectoral fins are fairly broad and long and fold against body; and the tips of pectorals, first dorsal, and first anal fins are pointed.

Subjective synonymy:

Histiophorus audax	Philippi, 1887
Istiophorus audax	Delfin, 1901
Tetrapterus mitsukurii	Jordan and Snyder, 1901
Tetrapturus ectenes	Jordan and Evermann, 1926
Makaira audax	Jordan and Evermann, 1926
Makaira grammatica	Jordan and Evermann, 1926
Makaira holei	Jordan and Evermann, 1926
Makaira mitsukurii	Jordan and Evermann, 1926
Makaira zelandica	Jordan and Evermann, 1926
Marlina mitsukurii	Grey, 1928
Marlina zelandica	Whitley, 1937
Kajikia mitsukurii	Hirasaka and Nakamura, 1947
Kajikia formosana	Hiraska and Nakamura, 1947
Tetrapturus tenuirostratus	Deraniyagala, 1951
Tetrapturus acutirostratus	Deraniyagala, 1952
Makaira formosana	Matsubara, 1955
Tetrapturus brevirostris	Munro, 1955
Marlina audax	Smith, 1956a, b
Marlina jauffreti	Smith, 1956b
Tetrapturus audax	Robins and de Sylva, 1960
Makaira jauffreti	Jones and Silas, 1964

Artificial key to genus (Nakamura et al., 1968):

A. Anterior fin rays of first dorsal fin fairly high, posterior rays about same height; vent situated decidedly anterior to origin of the first anal fin; second anal fin anterior to second dorsal fin.

  B. Pectoral fin narrow and short

    C. Snout very short. . . Shortbill spearfish (Furaikajiki) *T. angustirostris* Tanaka.

    CC. Snout fairly long . . . . Mediterranean spearfish (Chichukaifurai). *T. belone* Rafinesque.

  BB. Pectoral fin wide and long . . . . .Longbill spearfish (Kuchinagufurai) *T. pfluegeri* Robins and de Sylva.

AA. Height of anterior portion of first dorsal fin about same as the body depth but gradually decreasing in height posteriorly; vent directly anterior to the origin of the first anal fin; second dorsal fin and second anal fin in parallel positions.

  D. Pectoral fin wide and its tip rounded. The tip of the first dorsal fin and first anal fin rounded . . . . White marlin (Nishimakajiki) *T. albidus* Poey.

  DD. Pectoral fin narrow, and its tip pointed; the tips of the first dorsal fin and first anal fin pointed . . . . Striped marlin (Makajiki) *T. audax* (Philippi).

1.22 Taxonomic status

The species is established on the basis of morphology without breeding data.

The species may be polytypic (see 1.31 below).

1.23 Subspecies

No subspecies are recognized.

1.24 Standard common names and vernacular names

Country	*Standard common name*	*Vernacular name(s)*
Sri Lanka		Seraman Koppara
Chile		Pez aguja
China		Chi zuo fo yii
Japan	Makajiki	Maka, Kajiki, Kajikimaguro, Nairagi, Nairage, Nairanbo
Kenya		Nduaro
Mexico	Marlińrayado	Marliń, agujon, pez puereo
New Zealand	Striped marlin	New Zealand marlin
Philippines		Spearfish
Russia		Polosatii marlin
Taiwan	Hung ju chi yii	Hung ju ting pan
United States	Striped marlin	Pacific striped marlin, barred marlin, Pacific marlin, striped swordfish, spearfish, spikefish
Vietnam		Ca co Mitsukurii

1.3 Morphology

1.31 External morphology (for description of spawn, larvae, and adolescents, see 3.17, 3.22, 3.23).

Generalized: Gregory and Conrad (1939) provide a scale diagram of the striped marlin outline based on modal body proportions of 30 specimens from New Zealand and Australia using standard length as the basic body measurement. Thirty-eight measurements were made on each specimen and are published in absolute and as percentage of standard length along with total body weight.

Nakamura et al. (1968) provide the following description:

> *External Characters.* The first dorsal fin has 37-42 fin rays. The second dorsal fin has 6 soft rays. The first anal fin has 13-18 fin rays. The second anal fin has 5-6 soft rays. The pectoral fin has 18-22 soft rays. The ventral fin has one spine and 2 soft rays. The

> body is elongated (the body length is about 5.9-7.3 times the body depth) and is rather thick. The snout is long (the head length is about 0.88-0.99 times the length of the maxillary), and its cross-section is almost round. The body is densely covered with scales; the tips of the scales are pointed. Scales from specimens less than 1 meter in length do not have this species characteristic. There are small file-shaped teeth on both jaws and on the palate. The lateral lines on the sides curve over the pectoral fin and then continue in a straight line to the area of the caudal fin. The head is large (the body length is 3.6-3.8 times the length of the head). The eyes are moderately large. There is a relatively conspicuous crest on the outer edge of the head between the pre-occular region and the origin of the first dorsal fin. There are 2 scutes on each side of the tail near the caudal peduncle; the tail is strong and deeply forked. The pectoral fin, has a pointed tip and is located rather low on the body; it is shorter than the head (the head length is about 1.14-1.99 times the length of the pectoral fin). The first dorsal fin begins above the posterior end of the pre-opercle bone; its first few rays are larger than the body depth, but as it progresses towards the back, it gradually becomes shorter, ending just in front of the origin of the second dorsal fin. The tip of the first anal fin is pointed, large and sickle-shaped. The second dorsal fin and the second anal fin are about the same size and shape. The latter is located a little further forward on the body than the former. In spite of the fact that the ventral fin is longer than the pectoral fin in smaller specimens, the opposite is true for larger specimens. The fin membrane of the first dorsal fin is dark blue. The back of the body is dark blue with splotches of black on it; towards the ventral side of the body, 10 or more rows of cobalt-colored stripes are clearly visible. The other fins are blackish brown, or sometimes a dark blue. The bases of the first and second anal fins are silvery-white.

Morrow (1952a) published morphometric data on 49 specimens from New Zealand and later (Morrow, 1957) published extensive morphometric data and anal ray counts on 39 fish from Peru. These data include standard length as the basic body length measurement. Ueyanagi (1957b) presented morphometric data on young specimens, 80- to 180-cm eye-fork length, from the western North Pacific. Royce (1957) reported extensive morphometric data of 25 specimens from the central Pacific using fork length as the basic measurement but also giving standard length and eye-fork lengths for some specimens. He also published more limited data on 30 specimens measured by the Hawaii Division of Fish and Game. Kamimura and Honma (1958) published morphometric data on five characters using eye-fork length as the basic body measure for 56 fish south of the equator and 124 fish north of the equator in the western Pacific. Williams (1967) presented dorsal and anal fin ray counts of 13 specimens from East Africa. Merrett (1971) gives fin measurements on about 23 other specimens.

Counts have been given by several authors and are shown in Table 1.

Georgraphic variation: Geographic variation appears to be considerable. Morrow (1957) concluded that striped marlin from Peru and northern New Zealand represented separate and distinct populations based on significant differences in 11 morphometric and meristic characters as follows: average absolute lengths of pelvic fins, counts of spines and rays in the first anal fin, and the regressions of the following measurements on standard length: greatest body depth, length of base of second dorsal fin, length of base of first anal fin, width of base of pectoral fin, snout tip to origin of first dorsal fin, snout tip to origin of second dorsal fin, snout tip to origin of first anal fin, snout tip to posterior edge of operculum, snout tip to posterior end of maxillary. By a character index (CI) in which

$$\mathrm{CI} = \frac{\text{pelvic length}}{10} - \frac{100}{\mathrm{SL}}\ (\text{Depth} + \text{Length}$$

of anal base + Width of pectoral base), Morrow could separate correctly about 72% of the 69 specimens from which the index was derived. The New Zealand specimens tended to have character indices of considerably lower numerical value than the Peru specimens.

In the western Pacific (west of long. 170°W) Kamimura and Honma (1958) found a remarkable difference in the lengths of the pectoral fins between northern (lat. 30°-35°N) and southern (lat. 18°-25°S) striped marlin. Covariance analysis of regression of pectoral fin on eye-fork length showed no significant difference in slope of regression but a highly significant (0.01) difference in adjusted means. Also significant differences (0.05) were found for both regression coefficients and adjusted means for regressions of eye-to insertion of second dorsal on eye-fork length. From these differences these authors concluded northern and southern populations in the western Pacific were extremely separated. In intermediate waters of the northern hemisphere (lat. 5°-25°N) all but three fish had pectoral lengths clustered about the regression line for the northern population. The pectoral lengths of the other three fish, which were taken from lat. 5° to 15°N, were close to the regression line for the southern population and were presumed to have strayed from that population.

Honma and Kamimura (1958) supported the hypothesis of separate north and south populations in the western Pacific with the following observations:

a) a zone of low hook-rate along the equator separates the populations;
b) the main spawning grounds are widely separated and spawning seasons are a half-year apart;
c) the maximum size attained is much larger in the southern population;
d) adaptations of the two populations to environmental circumstances do not coincide in details, differing with growth stages.

Howard and Ueyanagi (1965) extended the

Table 1.—Fin-ray counts of *Tetrapturus audax*.

Area and author	First dorsal fin	Second dorsal fin	First anal fin	Second anal fin	Pelvic fins	Pectoral fins
Chile						
Philippi, 1887	38	5	12	5	1	
Western Pacific						
Nakamura, 1938, 1949	37-43 (III+12−15+XXII−XXV)	6	14-15 (II+12−13[1])	6	1+2	
Western Pacific						
Ueyanagi, 1959	37-44					
New Zealand						
Morrow, 1957			12-16			
Peru						
Morrow, 1957			14-17			
East Africa						
Williams, 1967	35-41	5-7	11-15	5-6		
Peru						
Morrow (unpubl.) (after Williams, 1967)	37-44	5-7	14-17	5-7		
East Africa						
Morrow (unpubl.) (after Williams, 1967)	36-41	5-7	11-15	5-6		
East Africa						
Merrett, 1971	38-42	5-7	13-16	5-6		19-23
Eastern North Pacific						
Wares and Sakagawa, 1974		5-7		5-7		

[1] The figure of 25 which appears here in the translation of the 1949 paper is evidently a misprint.

hypothesis by including eastern Pacific fish in the southern population and demonstrating that growth of the pectoral fin is allometric with an inflection at about 185-cm eye-fork length. They pointed out that mixing of the two populations occurs in the tropics and suggested that Mexican fish belong principally to the southern-eastern group and that southern California fish are derived from both groups but dominated by the northern.

Merrett (1971) found striped marlin of the tropical western Indian Ocean to have relatively long pectoral fins indicating a closer relation to the southern-eastern population than to the northern.

There has been little mention in the literature of geographical variation in color pattern, but the striking almost zebralike bars on the freshly caught New Zealand specimen in the photo published by Gregory and Conrad (1939) appears more pronounced than in fish from other regions.

To date, the knowledge of subpopulations, if they truly exist, is insufficient for morphological definition.

The morphological changes of larvae and adolescent phases are of course remarkable. See 3.22 and 3.23.

Morrow (1952a) found significant ($P < 0.001$) negative allometry in the dorsal and ventral lobes of the caudal fin and a slight but not statistically significant ($P = 0.065$) negative allometry in the length of the pectoral fin of 49 adult fish from Cape Brett, New Zealand. The pelvic fins show extreme negative allometry appearing to cease growth after reaching a certain size (Morrow, 1957; Royce, 1957). Negative allometry was found in Peruvian specimens for body depth and snout tip to origin of first anal fin (Morrow, 1957). Ueyanagi (1957b) found extreme negative and positive allometry, respectively, in central dorsal rays relative to body depth and pectoral length relative to body depth in young specimens (85-175 cm) which proved the synonymy of *Kajikia formosana* and *T. audax*. Royce (1957) also found similar allometry.

Ontogenetic change in body form is shown in Figure 1. The morphological change of the snout (its growth relative to the body length) from the postlarval to adult stage of striped marlin is relatively small in comparison with those of other istiophorid species. However, the change of the dorsal fin shape during growth is remarkable in this species (Ueyanagi, 1963b).

In relation to functional morphology, Fierstine (1968) found an average aspect ratio (span/surface area of one side of fin) of 9.0 for the caudal fin of three striped marlin from the eastern Pacific. This high ratio, indicating relative efficency as a hydrofoil, was greater than that for seven other scombroid species but less than that for the sailfish, *Istiophorus platypterus*, and the white marlin, *T. albidus* (10.0 and 10.3, respectively).

Published weight-length regression constants are summarized in Table 2.

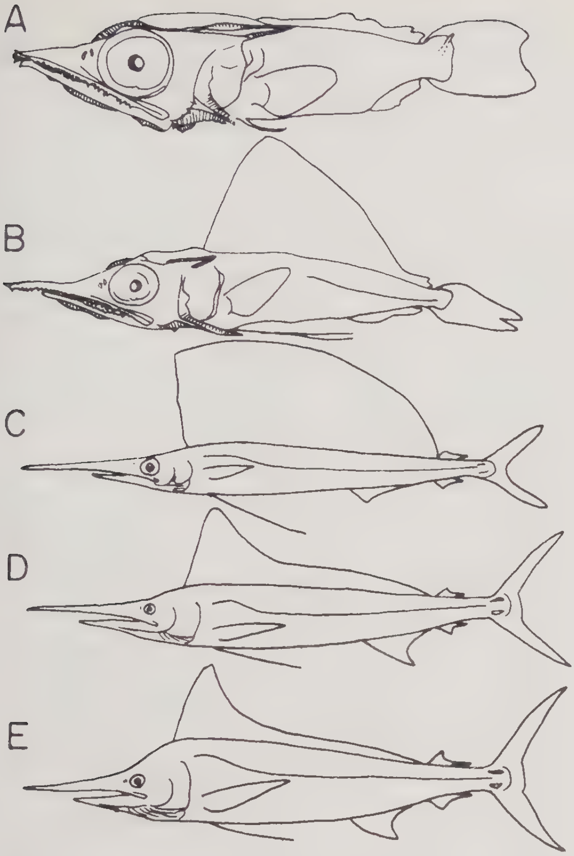

Figure 1.—Ontogenetic change in body form of striped marlin. A. 7.9 mm SL, B. 21.2 mm SL, C. 121.5 mm body length, D. 1,050 mm body length, E. 1,882 mm body length. (From Nakamura, 1968.)

1.32 Cytomorphology

No data available.

1.33 Protein specificity

No data available.

2 DISTRIBUTION

2.1 Total Area

In the eidogical classification of Parin (1968) the striped marlin is holoepipelagic, i.e., it inhabits the isothermic surface pelagic layer of the ocean at all stages of its life cycle. Such species are chiefly limited in distribution to the tropics, where a permanent thermocline exists, but penetrate higher latitudes in the warm season. Atypical of the distribution of most scombroids, the striped marlin seems to prefer the more temperate waters. In the Pacific the distribution resembles that of the albacore, *Thunnus alalunga*, and bluefin tuna, *T. thynnus*, in contrast to that of the other billfishes and tunas (Howard and Ueyanagi, 1965; Parin, 1968), however, in the Indian Ocean the striped marlin distribution is centered in warmer waters.

Striped marlin occur throughout the warmer waters of the Indian and Pacific oceans. The species ranges eastward to the coast of the American continents and westward to the African coast. Off South Africa they are found a slight distance into Atlantic waters (Talbot and Penrith, 1962). Extreme poleward distribution has been recorded to lat. 40°-45° in both hemispheres. In the north this occurs in the Kuroshio extension, primarily between long. 165°E and 180°, but also at long. 150°W (Fisheries Agency of Japan, Research Division, 1969-71). In the southern hemisphere this occurs in the Agulhas Current (Talbot and Penrith, 1962; Fisheries Agency of Japan, Research Division, 1969-72) and also rarely at long. 105°E (Fisheries Agency of Japan, Research Division, 1969), which appears to be West Wind Drift water. On the eastern perimeter of the Pacific, Point Conception (lat. 35°N) and Chañaral, Chile (lat. 29°S) appear to be the northern and southern limits of distribution.

The broad geographical distribution of this species makes it difficult to generalize on the physical and biological characteristics of the areas inhabited. Temperature, however, is one parameter which has been considered to influence total distribution. The 20° and 25°C isotherms tend generally to bound the total distribution at least in the western Pacific (Howard and Ueyanagi, 1965).

2.2 Differential Distribution

2.21 Spawn, larvae, and juveniles

Although information is lacking on the distribution of eggs, there are several reports (Ueyanagi, 1959, 1964; Jones and Kumaran, 1964; Nishikawa and Ueyanagi, 1969) pertaining to the distribution of larvae.

In the Pacific, larvae have been observed in the northwestern Pacific (west of long. 180°) between lat. 10° and 30°N; and in the South Pacific (west of long. 130°W) between lat. 10° and 30°S. The larvae are most abundant in early summer, with the peak occurrence in the northwestern Pacific during May-June, and in the South Pacific in November-December. The seasonal occurrence of mature females coincides with that of the larvae (Ueyanagi, 1964). While the distribution of larvae is not known for the

Table 2.—Weight-length constants for *Tetrapturus audax* ($\log W = \log a + b \log L$).

Location	Weight	Units of weight	Length	Units of length	Number	Approximate length range of specimens	a	b	s	Source
New Zealand and Australia	Whole	lb	FL[1]	cm	27	265-310	−6.515	3.624	0.045	Gregory and Conrad, 1939 (after Royce, 1957)
New Zealand	Whole	lb	FL[1]	cm	48	218-310	−5.024	3.011	0.056	Morrow, 1952a (after Royce, 1957)
Central Pacific	Whole	lb	FL	cm	13	142-304	−6.648	3.691	0.502	Royce, 1957
Hawaii	Whole[2]	lb	FL[3]	cm	30	166-253	−6.110	3.446	0.048	Hawaii Division of Fish and Game (after Royce, 1957)
East Africa	Whole	lb	FL	cm	98	170-270	−4.629	2.844	?	Williams, 1967
Fiji area	Gilled and gutted	kan[4]	Eye-fork[2]	cm	562	160-260	−6.737	3.504	?	Koga, 1967
Equatorial west Indian Ocean	Whole	lb	Eye-fork	cm	156	120-196	−4.782	[5]3.062	?	Merrett, 1968c
Eastern Pacific	Whole	kg	Eye-fork	cm	51	108-211	−5.255	3.089	?	Kume and Joseph, 1969b
Eastern Pacific	Whole	lb	Eye-fork	cm	1,982	110-215	−4.816	3.072		Wares and Sakagawa, 1974
Eastern Pacific	Whole	kg	Eye-fork	cm	1,982	110-215	−5.157	3.071		Wares and Sakagawa, 1974
Eastern Pacific	Whole	lb	FL	cm	535	153-271	−5.007	2.986		Wares and Sakagawa, 1974
Eastern Pacific	Whole	kg	FL	cm	535	153-271	−5.340	2.982		Wares and Sakagawa, 1974

[1] The original measurement was SL which apparently Royce converted to FL on the basis of regression for nine Hawaiian specimens and mislabeled "*total*" length in caption to Appendix Table 3-A.

[2] Presumed.

[3] The original measurement was naris to fork which Royce converted to FL on the basis of regression for 21 Hawaiian specimens.

[4] 1 kan = 3.75 kg = 8.287 lb.

[5] ±0.197.

eastern Pacific (east of long. 120°W), mature fish are reported to occur there between lat. 5° and 20°N, largely in May-June (Kume and Joseph, 1969b).

In the Indian Ocean, larvae have been reported to occur in the Banda and Timor seas during January to February (Ueyanagi, 1959), and in the western Indian Ocean during December to January between lat. 10°S and 18°S and in the eastern Indian Ocean during October to November between lat. 6°N and 6°S (Jones and Kumaran, 1964). Mature females are reported to occur in March-May in the Bay of Bengal although larval occurrence is not yet known there (Ueyanagi, 1964).

The lower temperature limit in the distribution of larvae is approximately 24°C both in the Indian and Pacific oceans. However, the distributions differ in that in the Pacific the larvae are scarcely found in equatorial waters. It is noted that striped marlin larvae are not likely to appear in the Kuroshio area, while sailfish larvae occur there exclusively (Ueyanagi, 1959).

Information is very sparse on the distribution of the juveniles. Nakamura (1968) reported on two juveniles (body length, 12.15 and 14.5 cm) found in stomachs of a yellowfin tuna, *Thunnas albacares*, and a dolphin, *Coryphaena hippurus*, taken by longline. One juvenile was found on 13 January 1955 at lat. 23°52′S, long. 175°49′W and the other on 21 December 1964 at lat. 17°57′S, long. 67°29′E. These two occurrences coincide with larval distributions in the South Pacific and Indian Ocean, respectively.

2.22 Adults

Major areas of high abundance are the western Arabian Sea, the central North Pacific (lat. 15°-30°N) and the eastern Pacific as shown in Figure 2. This figure shows distributions based on highest quarter-year hook rates by 5° squares for the years 1967-69 (Fisheries Agency of Japan, Research Division, 1969-72). Lesser areas of abundance occur off South Africa, northern Madagascar, northern Sumatra, Sri Lanka, eastern and western Australia, central Pacific coast of Japan, and the south central Pacific.

The high density in the Arabian Sea appears to be seasonal, occurring in the second quarter of the year. However, fishing effort in other seasons has been very slight. Off East Africa (lat. 0°-12°S) where striped marlin are the most abundant marlin, the works of Merrett (1968a, b) showed highest hook rates occurred between lat. 2° and 4°S. The hook rate was six times higher in the northeast monsoon (Nov.-Mar.) than in the southeast monsoon (Apr.-Oct.).

The season of high abundance off western and eastern Australia is the fourth quarter (Fisheries Agency of Japan, Research Division, 1969-72). Koga (1967) states, however, that good catches occur in winter off western Australia. In the South Pacific, Koga states that it is a remarkable feature that the main fishing areas, which show good catches from August to December, show very poor catches from January to July.

In the northwestern Pacific, striped marlin are abundant in Formosan waters, both in the Kuroshio and in the South China Sea, during the whole northeast monsoon season with a peak in the middle of that season. Later in the spring, they move north into the waters of Japan where they appear at about the same time as the albacore do (Nakamura, 1949).

In the Hawaiian area, striped marlin occur from fall through spring with the seasonal distribution being

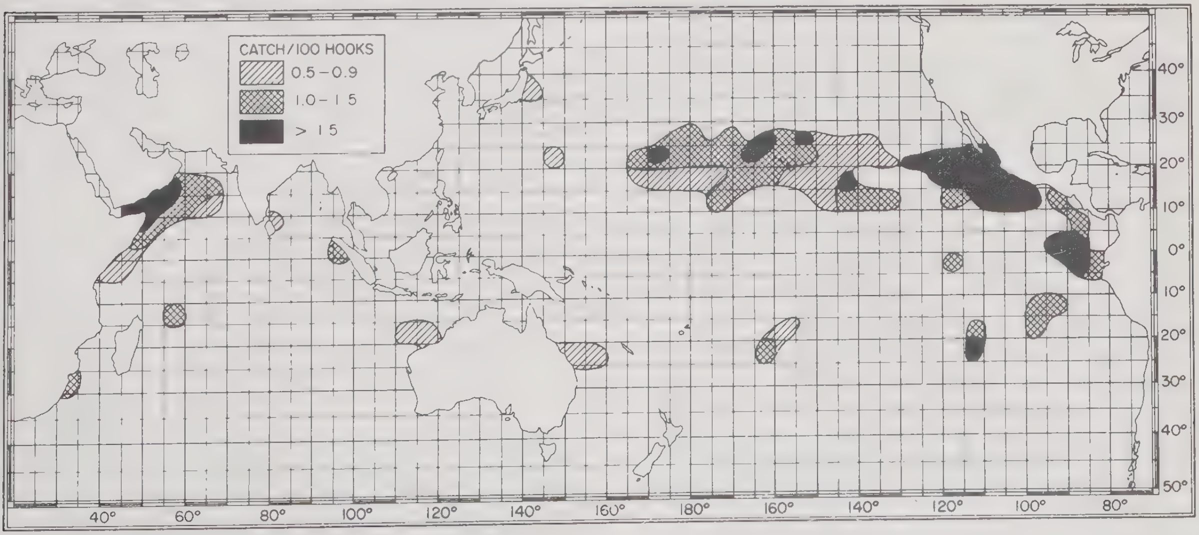

Figure 2.—Areas of high apparent abundance of striped marlin, 1967-69. (After Fisheries Agency of Japan, Research Division, 1969-72.)

complimentary to that of the blue marlin, *Makaira nigricans*, which occurs primarily in the summer (Strasburg, 1970).

In the eastern Pacific, striped marlin are present throughout the year from lat. 30°N to 30°S. High abundance is maintained throughout the year in the areas of the Revilla Gigedo Islands, Baja California, Ecuador, the Galapagos Islands, and in the high-sea area bounded by long. 90°-110°W and lat. 10°-30°S (Kume and Joseph, 1969b). Seasonal changes in apparent density are marked. The concentration between Baja California and the Revilla Gigedo Islands, which is restricted to a narrow band in the first quarter, expands southeast along the coast and seaward to long. 115°W during the second quarter, and then north to lat. 28°N, south to lat. 3°N and seaward to long. 125°W during the third quarter. During the fourth quarter the southern extension expands further to long. 130°W. Another seasonal concentration develops in the second and third quarters in the offshore area between long. 100° and 115°W centered at about lat. 8°-13°N. The area of high density around the Galapagos Islands extends eastward to the coast of Ecuador in the third and fourth quarters and then recedes again in the first.

The sport fisheries for striped marlin off Mexico and southern California are seasonal. In southern California it is highly seasonal with almost all fish being taken between August and October. In Mexico some fish may be taken year round, but the best fishing occurs from December through March at Mazatlán and April through August near the tip of Baja California (Eldridge and Wares, 1974).

In addition to differential distribution in density, there is also some differential distribution in size. In the eastern Pacific, fish on the southern spawning grounds are larger than those on the northern. The length frequency of the southern group has a single mode at 180-200 cm whereas that of the northern group has two modes, one at 140 cm and one at 180 cm (Kume and Joseph, 1969b). In the western Pacific latitudinal stratification occurs. Honma and Kamimura (1958) show small marlin occurring in equatorial waters; these small fish are absent in the region of lat. 5°-16°S. In mid-latitudes (15°-30°S) of the central South Pacific longitudinal stratification is apparent; larger fish (> 180 cm) occur in the western Pacific (Koga, 1967). There may also be some vertical stratification. Furukawa, Koto, and Kodama (1958) found harpooned fish to be larger than longline-caught fish in the East China Sea. The harpooned fish were also fatter at a given length.

Off Formosa the smaller fish, which were long thought to be the separate species *Kajikia formosana*, occur with the shortbill spearfish, *Tetrapturus angustirostris*, offshore from the center of the Kuroshio, while the larger fish occur inshore (Nakamura, 1949).

2.3 Determinants of Distribution Changes

Probably behavioristic factors related to feeding and reproduction are the primary determinants of changes in distribution. These in turn are affected by the seasonal cycle of warming of the surface waters, development of thermoclines and currents, and seasonal cycles in abundance of food organisms. The subject of the factors and relationships causing concentration of striped marlin has not received much discussion in the literature.

Nishimura and Abe (1971) have found a correlation between the position of the Kuroshio as indicated by the latitude at which the current crosses 139°30′E, and the catch made off Izu.

Kume and Joseph (1969b) noted that the appearance of the area of high hook rate centered at lat. 8°-13°N from long. 100° to 115°W is associated with the strong development of the Equatorial Countercurrent. They noted further that a diagonal band of high abundance extending from lat. 5°S, long. 120°W to lat. 8°S, long. 95°W was in the general region of the eastern extension of the South Equatorial Countercurrent.

In the area west of Australia, both the striped marlin and southern bluefin tuna grounds are centered at the boundary of currents which run along long. 115° E meridian in winter (Koga, 1967).

Manning (1957) states that off Chile, striped marlin are found in the green water that is normally found from shore to 10 to 25 miles offshore. Their occurrence in these waters was in common with bonito, sardines, and anchovies and in contrast to swordfish which occurred farther offshore in the blue and white waters.

Furukawa et al. (1958) show the fishing ground in the western Pacific associated with the surfacing of the 20°C isotherm over the edge of the continental shelf.

Nakamura (1938) states that surfacing of fish is associated with high waves generated by opposing wind and current as in the case of the Kuroshio and the northeast monsoon.

2.4 Hybridization

No record.

3 BIONOMICS AND LIFE HISTORY

3.1 Reproduction

3.11 Sexuality

Striped marlin are heterosexual with no reported intersexuality or hermaphroditism.

Sexual disorphism has not been reported in this species and the sexes are indistinguishable externally. Nakamura (1949) mentioned the sexual difference in body size is not great in the genus *Tetrapturus* in contrast to the case in *Makaira*. Differences in greatest size or modal size between the sexes are small. Ueyanagi (1953) found, in the northwestern Pacific, that the modal size of males is about 10 cm smaller than that of females. Koga (1967) showed a length-frequency distribution by sex for 210 fish from the Fiji area in which the modal lengths for males and females were 195 and 205 cm, respectively. In a sample of 105 striped marlin taken by longline off East Africa, Williams (1967) found males did not exceed 240 cm fork length (equivalent to 182 cm eye-fork length from regression of Merrett, 1971). About 16 females were taken above this length to a size of about 270 cm (205 cm eye-fork length). Merrett (1971), however, found males up to 193 cm eye-fork length off East Africa. Modal size differences between the sexes were not found in Hawaiian fish (Strasburg, 1970) nor in the eastern Pacific (Kume and Joseph, 1969b).

3.12 Maturity

As has been found in other pelagic species such as albacore and dolphin, quantitative measure of maturity for males is difficult. There is only a small increase in testis size during the maturation cycle. Merrett (1971) found little correlation between relative testis size and maturity-stages based on microscopic examinations. In fact, Merrett (1970) suggests that there is continuous availability of spermatozoa in mature males based on differential maturation of the testicular lobules and the possession of a muscular seminal vesicle.

In the female, maturation is synchronous throughout the ovary and seasonal maturation is accompanied by marked increase in relative size of the gonads. Data from Kume and Joseph (1969b) showed a twentyfold increase. Moreover, there is good correlation of relative ovary weight and mean maximum egg diameter (Merrett, 1971; Eldridge and Wares, 1974).

Williams (1967) concluded from longline data in East Africa that first maturity was reached between 180 and 200 cm fork length (50-80 lb) which is equivalent to 141-157 cm eye-fork length (Merrett, 1971). Merrett reported similar results, 140-160 cm or 62-93 pounds. Ueyanagi (1957b) mentioned that 154 cm eye-fork length was the smallest size found in the spawning group of the northwestern Pacific. Kume and Joseph (1969b), using a gonad index, reported that individuals from the eastern Pacific do not regularly enter the spawning group until reaching about 160 cm eye-fork length but found one as small as 148 cm. Other data from the eastern Pacific (Eldridge and Wares, 1974) agree with these conclusions.

Since age at specific size is not known for striped marlin, age at maturity is also unknown. Koga (1967), however, stated "it is likely that growth rate of this species shows different values between the Indian Ocean and the Pacific Ocean and the groups in the Indian Ocean attain maturity earlier than those in the Pacific."

3.13 Mating

Nothing has been published relating to mating habits of this species.

3.14 Fertilization

Fertilization is externally.

3.15 Gonads

Merrett (1970) has described the gonads of billfish in detail. The following description is taken from his work.

> The gonads are paired organs lying in the posterior half of the body cavity, on each side of the stomach and intestine. They are suspended from the lateral edges of the chambered air bladder by mesenteries . . . the gonads are almost bilaterally symmetrical and both terminate at their point of discharge to the exterior in the urino-genital papilla . . . which lies posterior to, and in a common groove with, the anus . . . The urinary and genital systems are closely linked.
>
> The ovaries are elongate sausage-shaped organs, which taper at both ends, and joined only at their posterior ends . . . A strong muscular sheath binds the ovaries to the urino-genital papilla and the basal part of the intestine. They are invested in thick layers of connective tissue which sometimes contain deposits of fat; fat is also occasionally found in the mesovarium. Beneath the connective tissue the ovaries are pale flesh-pink to wine red in colour, depending upon the stage of maturity. Internally, at certain stages, a central lumen runs the length of the ovary . . . the ovaries have been found to be unequal in length . . . either ovary can be the longer of a pair.
>
> . . . Immediately posterior to . . . [the anal papilla] . . . is the urino-genital papilla. In the female this carries only the urinary duct. The point of discharge of the ovaries is situated between the bases of the anal papilla and the urino-genital papilla.

This opening between the anal and urino-genital papillae which is absent in the males should serve as an external characteristic in distinguishing the sexes. But in the experience of the junior author this difference is difficult to observe consistently in this species. It is more obvious in the sailfish.

Nakamura (1949) stated that the fecundity of billfishes ranges from 1 to 1.2 million eggs, depending on fish size and species. Morrow (1964) estimated 2 million eggs for New Zealand marlins. These appear to be low estimates, however. Merrett (1971) reported an estimated fecundity of 12 million for one Indian Ocean specimen of 182 cm eye-fork length, 126 pounds with ovary weight of 1.53 kg, and mean maximum egg diameter of 0.470 mm. Eldridge and Wares (1974) reported fecundity estimates of three eastern Pacific specimens which ranged from 11 to 29 million eggs. These fish ranged in size from 150 to 180 cm eye-fork length but the fecundities showed no relation to size of the fish. Gosline and Brock (1960) estimated 13.8

million eggs were contained in one ovary of a 154-pound striped marlin landed in Honolulu. The other ovary of this fish was immature.

3.16 Spawning

Examination of size-frequency distributions of egg diameters (Eldridge and Wares, 1974) indicates only one spawning per season.

In the western Indian Ocean it appears that the high catch rates during the northeast monsoon period which peak from December to February are associated with a postspawning feeding migration (Williams, 1967; Merrett, 1971). Spawning must occur elsewhere in the Indian Ocean.

From larval occurrence, spawning was suggested to take place in the Banda and Timor seas during January to February (Ueyanagi, 1959). On the basis of larval occurrence, Jones and Kumaran (1964) stated that striped marlin spawn in the western Indian Ocean during December-January between lat. 10° and 18°S and in the eastern Indian Ocean during October-November between lat. 6°N and 10°S. Furthermore mature females are known to occur in March-May in the Bay of Bengal and in October-December in the waters south of the Lesser Sunda Islands (Ueyanagi, 1964).

In the western Pacific, mature females are found from lat. 15° to 30° (north and south) in early summer, from May to June and October to January in the northern and southern hemispheres, respectively. Larvae are also found in these areas (Ueyanagi, 1964). Nakamura (1949) stated that in the Formosa area, spawning is thought to take place mainly in the South China Sea with its peak occurring from April to May. Koga (1967) reported that the spawning areas (lat. 18°-30°S) in the western South Pacific is also the main fishing area and that the period of spawning corresponds to the season of northward migration which occurs from September to November.

In the eastern Pacific, the spawning season also appears to be the early summer in each hemisphere, quarters II and III in the northern and quarters IV and I in the southern. Highest frequencies of spawning fish occur from May to June in the north and November to December in the south (Kume and Joseph, 1969b). Evidence of spawning in the eastern Pacific is based only on relative gonad sizes of females. The northern spawning area appears to be isolated in a narrow band from long. 107° to 114°W extending from about lat. 6° to 19°N (Kume and Joseph, 1969b).

Ovaries of striped marlin caught in the Mexican sport fishery undergo rapid development in June; ripe fish were never observed (Eldridge and Wares, 1974). Japanese fishermen, however, have reported ripe and running ripe striped marlin in the waters around Socorro Island from June to October (J. L. Squire, Jr., Southwest Fisheries Center, National Marine Fisheries Service, NOAA, La Jolla, Calif., pers. commun.).

The southern spawning area appears fairly well confined to lat. 20°-25°S and long. 125°-130°W (Kume and Joseph, 1969b). Highest frequencies of the mature females occur in November and December.

Nakamura (1949) stated that sex ratios approached 1:1 at the peak of the spawning season. However, it was found that males dominate during the spawning season in the northwestern Pacific (Nakamura, Yabuta, and Ueyanagi, 1953). Kuma and Joseph (1969b) also found a high proportion of males in the spawning groups in the eastern Pacific. Male:female ratios ranged from 1.8 to 6.6 in spawning groups, whereas in nonspawning groups they tended to be less than 0.5 and to decrease with increased size of fish.

3.17 Spawn

There is little information pertaining to the eggs of this species. Nakamura (1949) mentioned that the external morphology of the eggs of striped marlin closely resembles that of sailfish eggs which are spherical, transparent, and buoyant, with a single oil globule and with no special structure on the egg membrane. Morrow (1964) reported that the ovarian eggs of striped marlin from New Zealand average about 0.85 mm in diameter. Size of the ovulated eggs of this species is presumed to exceed 1 mm in diameter considering that the mean diameter of eggs for shortbill spearfish is 1.442 mm and for sailfish is 1.304 mm as reported by Merrett (1970).

3.2 Pre-Adult Phase

3.21 Embryonic phase

No information available.

3.22 Larval phase

The postlarval stage of striped marlin is described in detail by Ueyanagi (1959). The study was based on 40 specimens ranging from 2.9 to 21.2 mm in standard length, collected from the northwestern Pacific, South Pacific, and the Indian Ocean. These specimens were captured by surface tows of the larvae net. The morphology of the striped marlin postlarvae is similar to that of other istiophorid species in the development and degeneration of head spination, fin formation, pigmentation, etc. Figure 3 from Ueyanagi (1959, 1963a) represents the postlarval stage of this species from an early stage with short snout to an advanced stage with elongated jaws. The snout begins to lengthen at around 7 mm standard length. Head spination becomes most conspicuous at this size. Fin rays of each fin reach their full complement at around 20 mm standard length. Pigmentation extends almost all over the body surface and on the dorsal fin membrane at this size. The dorsal fin begins to increase its height at around 10 mm and stands very high like a sail in larvae exceeding 20 mm. The key diagnostic character for the striped marlin larvae was reported as

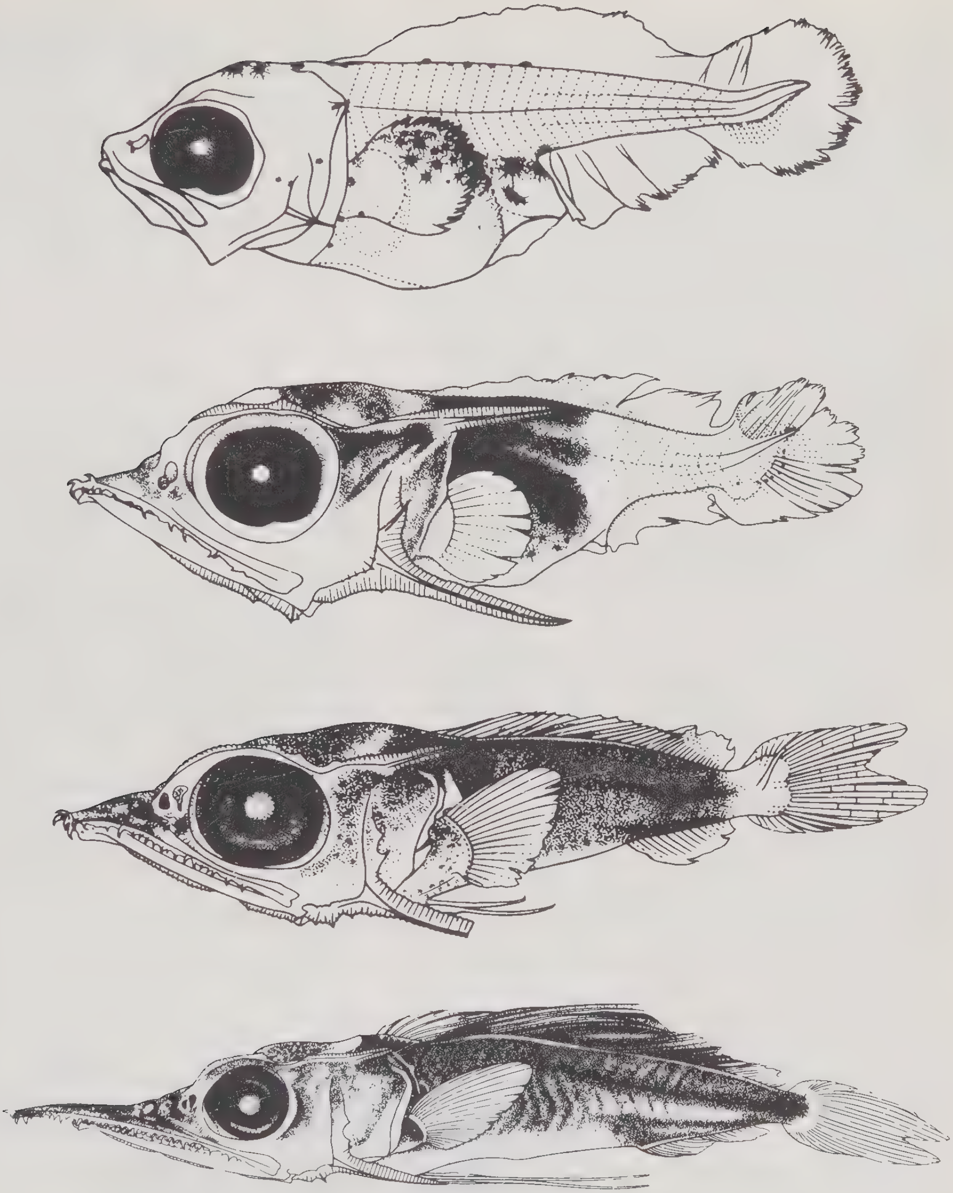

Figure 3.—Larvae of striped marlin. From top to bottom: 2.9, 5.0, 12.0, and 21.2 mm SL. (From Ueyanagi, 1959, 1963a.)

follows: ". . . the profile of head, tip of snout and center of eye are on a nearly equal level" (Ueyanagi, 1963a). In addition, the shape (arrangement) of the pterotic and preopercular spines is diagnostic for larval identification (Ueyanagi, 1974).

On the vertical distribution of billfish larvae, Ueyanagi (1964) indicated that larvae appear to be distributed most abundantly in the surface layer during the daytime and vertical, diurnal migration seems to occur in the upper 50 m of waters (Table 3.). Billfish larvae appear from time to time in the stomach contents of the larvae and juveniles of sailfish and swordfish, *Xiphias gladius* (Arata, 1954; Gehringer, 1956). It is assumed that striped marlin larvae are therefore preyed upon by many surface feeding species, including the billfishes. Considering the very large numbers of eggs spawned by the striped marlin (see 3.15), it appears that mortality at the larval stage is extremely high.

Time of first feeding: No direct information is available. There is an observation that five copepods were seen in the stomach of a 3.9-mm sailfish larva (Gehringer, 1956).

Type of feeding: There is no information pertaining to the larvae of striped marlin. Of the larvae of sailfish in the Atlantic, Gehringer (1956) noted that "copepods constituted the food of specimens less than 6 mm. long. At this size fish larvae also were eaten, and no specimen exceeding 13 mm. had copepods in its stomach." Furthermore, it is also known that sailfish larvae have consumed istiophorid larvae half as long as their own body length. It is believed that the larvae of striped marlin, like the sailfish, begin to feed on fish larvae after reaching a size of about 7 mm.

Table 3.—Comparison of numbers (and percentage) of tows from which istiophorid larvae were captured, showing the various depths and times of towing, in the western Pacific area. (From Ueyanagi, 1964.)

Depth (m)	32 day tows		31 night tows	
	Number	Percent	Number	Percent
0	22	68.8	12	38.7
ca. 20	8	25.0	12	38.7
40-50	2	6.2	10	32.3

3.23 Adolescent phase

Nakamura (1968) described the juveniles of striped marlin based on two specimens collected from the South Pacific and the western Indian Ocean (see 2.21). His drawing has been reproduced as Figure 4. In the juvenile stage the snout is very elongate and, in fact, is longest at this stage relative to body length. The shape of the first dorsal fin still differs from the adult configuration, being highest anteriorly and decreasing gradually in height posterioriy. The arrangement of the viscera is similar to that of the adult. Nakamura also mentioned that the juvenile of striped marlin is similar to that of the white marlin in many respects except that the former has no ocelli on the first dorsal fin.

It is believed that large, powerful pelagic fishes such as tunas, billfishes, dolphins, etc., are the principal predators of juvenile striped marlin.

Little is known about parasites in juvenile striped marlin.

Immature striped marlin (80-100 cm eye-fork

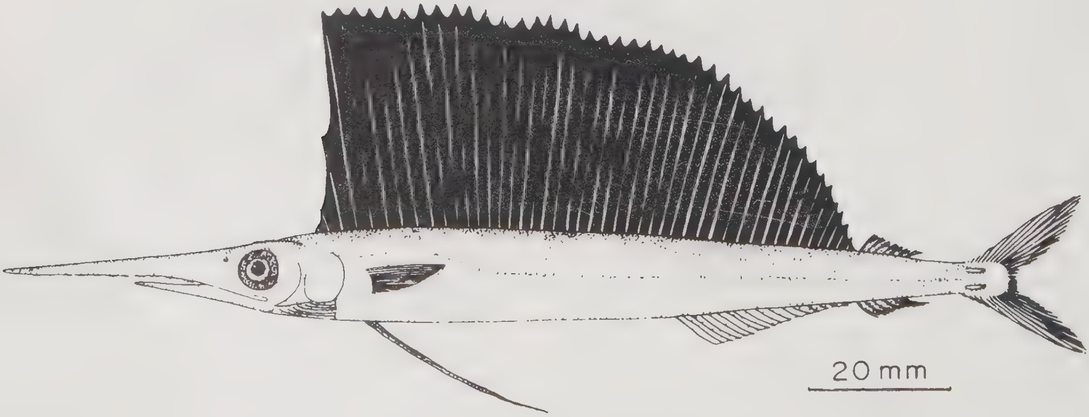

Figure 4.—Juvenile striped marlin (121.5 mm body length) collected from the southwestern Indian Ocean. (From Nakamura, 1968.)

length) are taken by longline. The shape of the first dorsal fin in these fish differs from the adults in that the posterior rays are still high (Ueyanagi, 1957b). Fish and squid are found in the stomachs, as in the adults.

Following the 1954 hydrogen bomb test in Bikini, it was reported that virtually all of the radioactively contaminated striped marlin found in the northwestern Pacific were fish under 130 cm long (Anon., 1955). It is not clear what the implications are with respect to ecological differences between young and adult fish.

3.3 Adult Phase (Mature Fish)

3.31 Longevity

The ability to determine age of individual striped marlin has not been developed and thus life tables cannot be developed and life expectancy and maximum age are unknown.

Koto (1963a), using size-frequency data from western Pacific catches, was able to discern six age classes (which he designates as n though $n + 5$) in fish greater than 100 cm eye-fork length. The Walford growth transformation of his data indicated an ultimate size of about 290 cm. Specimens of this size are apparently occasionally taken in the South Pacific (Honma and Kamimura, 1958). From the general pattern of growth indicated by Koto, fish of this size would be expected to be at least 10 yr old.

3.32 Hardiness

Very little is known. Because of the large size and activity of this species, physiological experimentation is difficult. The return rate for tagged fish is much higher for striped marlin than for sailfish (Squire, 1974), and this may indicate greater general hardiness for striped marlin. Healing of severely broken bills (Wisner, 1958) may also be an indication of hardiness. Sportsmen usually report that the striped marlin fights harder than the sailfish when hooked and tends not to die as easily as the sailfish.

3.33 Competitors

The other billfishes, particularly the smaller species (sailfish and probably the shortbill spearfish), swordfish, and the larger tunas are probably the closest competitors for food. Even the smaller scombrids share many forage species with the striped marlin. The dolphin and pelagic sharks such as *Prionace*, *Carcharhinus*, and *Isurus* utilize many of the same forage species (Parin, 1968). Striped marlin tend to feed more on epipelagic species and less on mesopelagic species than the oceanic tunas or the swordfish.

3.34 Predators

Predators of adults are probably extremely limited, the only likely candidates being some of the large pelagic sharks and the toothed whales.

Bills of billfishes have been found in floating objects and other fish. Occasionally bills of striped marlin are found to have been broken off, and the fish are known sometimes to ram fishing boats when hooked, but it is not certain that any of these occurrences have any relation to defense or aggressive action.

3.35 Parasites, diseases, injuries, and abnormalities

Parasites and diseases: The body surface usually harbors many caligoid copepods which frequently congregate on the ventral surface, particularly in the area around the anal fin and on the head. Williams (1967) reports they may occur in the thousands. The skin surface in areas of concentration often appears red and irritated. Penellid copepods (*Penella fillosa*) are frequently found penetrating the skin and anchored in the muscle or sometimes in internal organs such as the gonads. Koga (1967) reports the percentage occurrence of caligoid copepods and penellid copepods on striped marlin in Fiji waters was 100% and 20%, respectively. Eldridge and Wares (1974) report the percent occurrence of penellids above and below the lateral line on one side of the body as 26.2% and 22.8% with average infections of 3.3 and 2.3 copepods per fish. Stalked barnacles (*Conchoderma irgatum*) frequently are attached to the penellid copepods and often to the marlin skin, normally near the vent (Williams, 1967). Digenetic trematodes were reported found on the gills by Williams (1967). Monogenetic trematodes of the family Capsalidae are quite common on the surface of the skin (Eldridge and Wares, 1974).

Cestode worms resembling *Dibothrium manubriformes* have been found in the intestines and nematodes (*Contracaecum incurvum*) are very common in the stomach occurring in densities greater than 200 per stomach (Morrow, 1952b). The copepod, *Philichthys xiphiae*, has been found in the mucus canals of the preopercular and opercular bones, and capsalid trematodes are commonly found in the nasal capsule (Eldridge and Wares, 1974).

Injuries and abnormalities: Gastric ulcers were reported in 14% of 563 eastern Pacific striped marlin (Evans and Wares, 1972). These may be associated with the presence of nematodes (R. T. B. Iversen, Southwest Region, National Marine Fisheries Service, NOAA, Honolulu, Hawaii, pers. commun.). The small squaloid shark (*Isistius brasiliensis*), the probable cause of crater wounds on many pelagic fishes including istiophorids (Jones, 1971), probably parasitizes striped marlin.

There is evidently little ability for regeneration as broken bills and pelvic fins are seen to heal over rather than regenerate. Striped marlin have recovered after losing almost all of the bill (Wisner, 1958).

3.4 Nutrition and Growth

3.41 Feeding

Most active feeding probably takes place in the morning. LaMonte (1955) reported that squid found in the stomachs of striped marlin off Peru and Chile were less digested in fish caught in the morning than those landed after noon. Kobayashi and Yamaguchi (1971), examining only fish caught after noon, found a decline in feeding activity toward sunset. Williams (1967), however, suggests that East African fish feed at any time of the day or night.

Apparently the food is usually captured by grasping with the mandibles rather than by spearing, slashing, or clubbing with the bill. Fish which have lost the bill completely survived well. Some food specimens are occasionally found, however, which have been neatly speared (Wisner, 1958; Evans and Wares, 1972).

3.42 Food

Several authors have reported on food habits. Table 4 gives an idea of the variety of food species which have been found most important in different studies. It is notable that, despite the large size and lack of gill rakers in striped marlin, relatively small forage items are commonly taken (Nakamura, 1949).

Food habits do not appear to vary appreciably with sex or size over the range of sizes commonly caught. Considerable variation in species composition of the diet occurs, however, with season and geographic location (Evans and Wares, 1972). Such variations probably reflect variations in availability of the food organisms in keeping with the generally accepted concept that these fish are broadly carnivorous, nonselective feeders. This is true of epipelagic fishes generally (Parin, 1968).

The average volume of food found in stomachs of striped marlin caught by the eastern Pacific sport fishery ranged from 14 to 23 fluid ounces per stomach (Evans and Wares, 1972). Yamaguchi (1969) reports that empty stomachs were found in 66% of striped marlin caught by longline. This percentage tends to be larger in billfish than in tunas. Evans and Wares (1972) found 19% empty stomachs.

3.43 Growth rate

Weight-frequency modal progressions in Hawaii landing data suggest an annual growth rate of about 30 pounds (Royce, 1957). Merrett (1971) found agreement with Royce's data in size-frequency distributions from East Africa. Possible modal lengths of about 152, 167, 177, and 197 cm eye-fork length were found in the length-frequency distribution for the total catch. Computed weights at modal lengths gave annual weight increments of 27, 21, and 23 pounds.

Table 4.—Some reported major food species for striped marlin.

Area	Food species	Author
East Africa	*Fistularia* sp. *Auxis* sp. Squid	Williams, 1967
New Zealand	*Scomberesox saurus* *Arripis trutta* *Loligo* sp.	Morrow, 1952b
New Zealand	*Ommastrephes sloani* *Caranx lutescens* *Scomber japonicus*	Baker, 1966
Tasman Sea	*Alepisauridae* *Clupeidae*	Koga, 1968
Bonin Islands	*Gempylus* sp. Cephalopods *Pseudoscopelus* sp. *Alepisaurus* *Ostracion* Crustacea	Yabuta, 1953
California	*Cololabis saira* *Engraulis mordax* *Sardinops caerulea*	Hubbs and Wisner, 1953
California	*Engraulis mordax* *Trachurus symmetricus*	Evans and Wares, 1972 Craig, 1972
Mazatlán, Mexico	Squid *Etrumeus teres* *Fistularia* *Argonauta* sp.	Evans and Wares, 1972
Baja California, Mexico	Squid *Etrumeus teres* *Scomber japonicus* *Fistularia* sp.	Evans and Wares, 1972
Peru-Chile	Squid	LaMonte, 1955
Chile	*Engraulis ringens* *Trachurus symmetricus* Squid	de Sylva, 1962

Koto (1963a) working with length-frequency data from the western North Pacific, found six modal groups (n though $n+5$). The monthly progression of these modes is shown in Figure 5. The designations of these modal groups are as follows:

Group	*Lengths* (cm)	*Increment* (cm)
n	100-120	?
$n+1$	120-160	35
$n+2$	160-185	27
$n+3$	185-205	19
$n+4$	205-220	16
$n+5$	220-233	13

There is a marked seasonal change in growth rate with rapid growth occurring from June to November and very little growth in the remainer of the year for age groups $n+1$, $n+2$, and $n+3$. Age group n appears

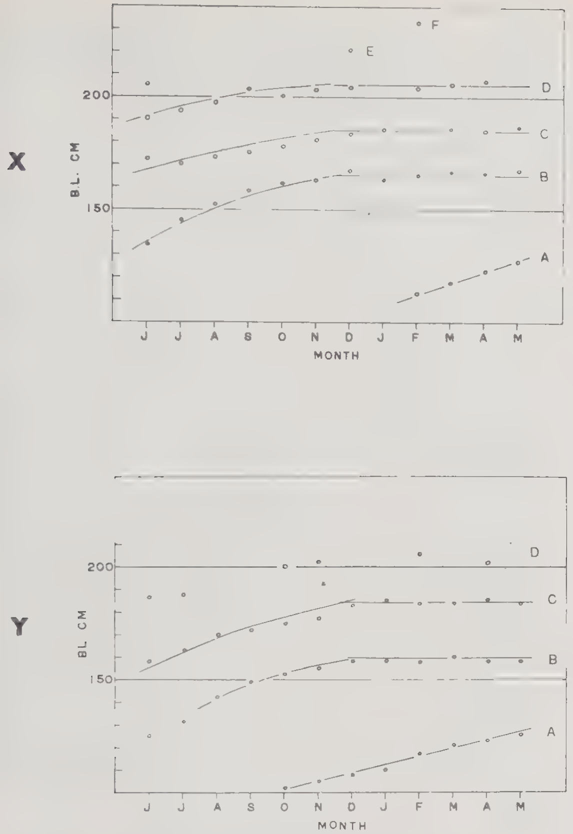

Figure 5.—Seasonal changes in modes derived from average year's length frequencies of longline-caught striped marlin. A. North Pacific Current area; B. East China Sea (long. 120°-130°E). (From Koto, 1963a.)

in the catch only after September, as fish larger than 100 cm and shows rapid growth right through the winter. The failure of the fishery to capture many fish below 100 cm makes it impossible to say what the absolute ages of the groups are.

The annual growths of the $n+1$ and $n+2$ age groups differ between areas and years. Koto (1963b) showed that in the North Pacific Current area the yearly differences in the length composition were caused by differences in the average length of the $n+1$ age group. In the North Equatorial Current area, however, these differences were probably caused by differences in age composition and the relative abundance of the n and $n+1$ age groups.

Koto (1963b) has shown growth rate to be affected by population density. The very close inverse relationship between growth of the $n+1$ age group and the total fish abundance, or especially the abundance of the n and $n+1$ groups is shown in Figure 6. The correlation coefficients between growth of the $n+1$ age group and total fish abundance were -0.958 (df = 6) for the North Equatorial Current area and -0.737 (df = 8) for the North Pacific Current areas.

Royce (1957) suggested the maximum size reached by striped marlin is less than 226.8 kg (500 pounds). Records were given as follows: 172.8 kg (381 pounds) off New Zealand; 142.4 kg (314 pounds) from Pacific equator; a "questionable" record of 196.9 kg (434 pounds) from the Hawaiian market, where normally only occasional specimens approach 136.1 kg (300 pounds); a somewhat questionable record because of possible confusion with the blue marlin of 219.1 kg (483 pounds) from Chile; the world's record, taken off California, was 692 pounds, which was based on a misidentified blue marlin.

The theoretical maximum length of about 290 cm mentioned in section 3.31 is equivalent to 259.5 kg (572 pounds). A fish of 290 cm was taken by longline in the South Pacific (Honma and Kamimura, 1958).

Average semimonthly condition factors (K) computed

$$K = \frac{W \times 10^5}{L^3}$$

where W is whole fish weight in kg
L is eye-fork length in cm

for eastern Pacific fish ranged approximately from 0.80 to 1.26 (Eldridge and Wares, 1974).

In the East China Sea, condition factor

$$K = \frac{W}{L^3}$$

where W = gilled and gutted weight in kan (= 3.75 kg)
L = eye-fork length in m

was found to increase with body length from about 8 at 110 cm to a peak of about 10 at 180 cm and then to decline to about 9 with larger fish up to 230 cm

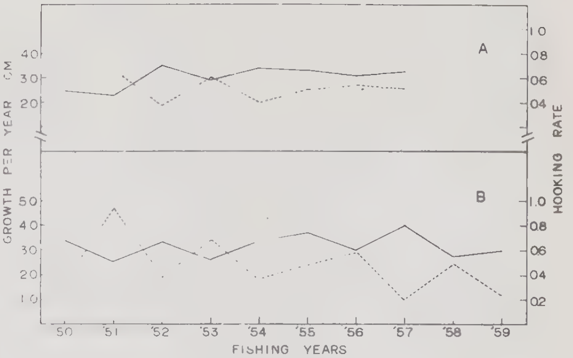

Figure 6.—Relation between total fish abundance and growth of the $n+1$ age group. A North Equatorial Current area; B. North Pacific Current area. —— growth per year; ……hook rate. (From Koto, 1963b.)

(Furukawa et al., 1958). The condition factor also showed a seasonal drop from about 10.8 in December to about 8.7 in June for fish of body length 166-195 cm. The drop in condition factor before June was much more abrupt than the increase after June. A similar seasonal cycle was also apparent for fish of 136-165 cm.

3.44 Metabolism

There are no data on metabolic rates for this species. Lindsey (1968) found body muscle temperatures as much as 2.6°C higher than the surrounding seawater. The highest temperature recorded occurred near the center of the epaxial muscle mass with a lesser maximum slightly below the hypaxial muscle mass center. Red muscle was found to be lower than white muscle at comparable depths beneath the skin. Temperatures of the viscera exceeded seawater temperatures by 0.7-1.3°C.

Barrett and Williams (1965) report the mean hemoglobin content in 16 striped marlin was 11.3 ± 0.75 g Hb/100 ml and ranged from 5.8 to 16.8.

3.5 Behavior

For feeding behavior, see 3.41; for reproductive behavior see 3.13, 3.21.

3.51 Migrations and local movements

See also 2.22 and 2.3.

The migration pattern of striped marlin appears to be principally a simple latitudinal movement between spawning areas and productive feeding areas (Parin, 1968). The movement is toward higher latitudes in the summer of each hemisphere and back toward equatorial waters in winter. In the northern hemisphere the peak of the northward migration is August-September and the southward migration begins in October and continues through February. The northward movement is also accompanied by an eastward expansion in the eastern Pacific (Howard and Ueyanagi, 1965; Fisheries Agency of Japan, Research Division, 1969-72).

In the central North Pacific small fish of about 13.6 kg (30 pounds) appear in Hawaii in winter, grow to 22.7-27.2 kg (50-60 pounds) by May or June, then migrate north for several months, and return to Hawaii as larger fish the next year. A similar pattern of migration is common to areas west of long. 180° (Howard and Ueyanagi, 1965).

In the southern hemisphere west of long. 150°W fish migrate north from south of lat. 30°S from August through November and form concentrations which are exploited in the area lat. 18°-19°S. The period of this migration corresponds to the spawning season. After November the fish appear to migrate south (Koga, 1967).

In the eastern South Pacific a high density area, which occurs in the area lat. 10°-17°S, long. 90°-115°W during the second and third quarters, appears to move southwest to the region of lat. 20°-28°S, long. 100°-110°W in the fourth and first quarters (Kume and Joseph, 1969a, b).

In the eastern North Pacific the seasonal north-south movements are apparent but less pronounced. Striped marlin do occur in their extreme northern range (southern California) during late summer and fall when surface temperatures reach a peak, but it is not clear whether these fish have come from the south or from the west (Howard and Ueyanagi, 1965). Data from fish tagged in the sport fisheries of southern California and Mexico provide evidence that striped marlin are capable of fairly long migratory movements up to 3,000 miles (Fig. 7). Some fish do move from California southward to the tip of Baja California and further, but there is no evidence of migration from Mexican waters to southern California (Squire, 1974).

Howard and Ueyanagi (1965) suggested on the basis of the appearance of an unusually small size group in California in 1958 and subsequent appearance 2 yr later of a small group in New Zealand, which was of a size expected for fish 2 yr older than the former, that there may be transpacific interchange between these remote areas.

Following the 1954 hydrogen bomb test in Bikini, contaminated fish were found only from the North Pacific, suggesting the possibility of separate populations in the two hemispheres (Nakamura, 1969).

In addition to the primary migratory trend, there are also lesser local movements reported. The area of high density off the central Mexican coast generally tends to expand westward seasonally reaching its maximum westward extent at about long. 130°W during the fourth quarter of the year (Kume and Joseph, 1969a, b). The region of high density around the Galapagos Islands during the second and third quarters expands eastward to the coast of Ecuador during the fourth and first quarters (Kume and Joseph, 1969a, b; Kume and Schaefer, 1966).

Nakamura (1949) mentions dense schools move from south to north along the coast of Vietnam in March and April.

In the western Pacific, Furukawa et al. (1958) report a gradual westward migration of fish from the vicinity of the Bonin Islands to the East China Sea in July and August where they stay until November after which a southward emigration takes place.

Migratory patterns in the Indian Ocean are unknown. The seasonal increase in density off East Africa during the northeast monsoon is believed to be a postspawning feeding migration (Williams, 1967; Merrett, 1971). The north-south type of seasonal movements that are typical in the Pacific are most evident off South Africa. A northward movement in the springtime (second quarter) is evident in the

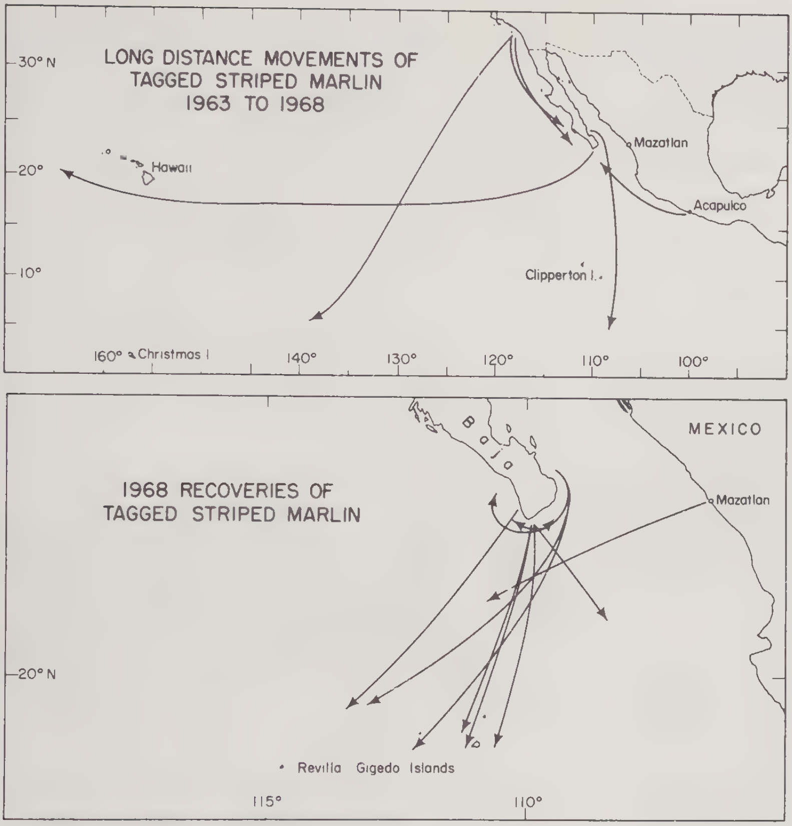

Figure 7.—Movements of tagged striped marlin in the eastern Pacific Ocean.

western Arabian Sea (Fisheries Agency of Japan, Research Division, 1969-72).

3.52 Schooling

Striped marlin, like the other istiophorids, do not form dense schools like the tuna, and the individuals are usually dispersed at wide intervals (Nakamura, 1949). Frequently, however, several fish are seen together; sometimes following one another, especially during the spawning season.

Surfacing is apparently more common when the wind and waves are high. When wind and current are moving in the same direction, the surface is calm and few fish are seen at the surface. When the wind runs counter to the current, high waves result, and fish are most often seen at the surface and are usually swimming in the direction of the wind, at least in Formosan waters (Nakamura, 1938).

When surfaced, the striped marlin usually is swimming very slowly with the upper caudal lobe above the surface and the dorsal fin retracted and not showing. This characteristic reportedly distinguishes them from swordfish which are unable to depress the dorsal fin and show both the dorsal and caudal fins when surfaced. Striped marlin swim faster and are less easily approached when surfaced than the swordfish (Philippi, 1887).

Little is known about how far the fish move vertically. Saito et al. (1972) report that striped marlin have been caught at 150- to 290-m depths by vertical longline experiments in Fiji waters.

For composition of stocks by size see also section 2.22. As mentioned previously, there is considerable variation in size composition between various regions and particularly between the northern and southern groups in the Pacific (see, for example, Howard and Ueyanagi, 1965; Koga, 1967; and Kume and Joseph, 1969b). As mentioned earlier, southern fish tend to be larger than northern fish throughout the Pacific. Size composition of striped marlin in the Indian Ocean resembles the North Pacific size distribution more than the South Pacific.

Striped marlin "schools" occur in waters in common with the schools of most of the Indo-Pacific scombroids, particularly albacore, yellowfin tuna, and bigeye tuna, *Thunnus obesus.*

3.53 Responses to stimuli

Very little is known of this subject as it relates to striped marlin. The possible response to temperature has been mentioned previously. It may be pertinent to note here that when billfishes are caught by hook or harpoon, they first make several leaps into the air and then swim wildly in broad circles near the surface. Tunas, on the other hand, try to escape in a vertical direction by diving deep (Nakamura, 1949).

4 POPULATION

4.1 Structure

4.11 Sex ratio

Sex ratio of the population as a whole is unknown; but from the data of Williams (1967), Kume and Joseph (1969b), and Merrett (1971), females usually predominate in longline catches. The notable exception to this is on the spawning grounds, where males tend to predominate (Kume and Joseph, 1969b). The percentage of females tends to increase with size of fish (Kume and Joseph, 1969b). There is a tendency for spawning grounds to be dominated by larger fish than in nonspawning areas.

4.12 Age composition

Since age determination of individual fish is not possible at present, age composition of the population has not been studied. See 3.43 on growth rate.

4.13 Size composition

Size composition varies greatly between stocks and with seasons (see 3.52).

Size at first capture by tuna longline gear is about 80 cm eye-fork length.

Size at first maturity is between 140 and 160 cm eye-fork length.

Maximum size is probably about 290 cm eye-fork length or 258.6 kg (570 pounds).

See 1.31 for length-weight relationships.

4.2 Abundance and Density (of Population)

4.21 Average abundance

No data.

4.22 Changes in abundance

Relative abundance in terms of average CPUE (catch per unit of effort) for major ocean areas is shown in Table 5 for the years 1962-70. These data show no apparent trend for the eastern, northern or the Pacific Ocean at large, however, there is a general decline noted for the South Pacific and a slight decline in the Indian Ocean, the latter since 1966 (Fisheries Agency of Japan, Research Division, 1965-72).

Year-to-year changes in CPUE for the various

Table 5.—Catch statistics by major ocean areas of Japanese longline fishery for striped marlin for 1962-1970 (Fisheries Agency of Japan, Research Division, 1965-72).

	1962	1963	1964	1965	1966	1967	1968	1969	1970
Indian Ocean									
E[1]	68.4	57.3	68.9	79.9	89.6	126	119	101	78
C[2]	48	34	38	81	106	114	63	59	45
CPUE[3]	0.07	0.06	0.06	0.10	0.12	0.09	0.05	0.06	0.06
Whole Pacific									
E	290	337	283	288	301	306	286	306	282
C	287	338	508	421	351	406	506	323	450
CPUE	0.10	0.10	0.18	0.14	0.12	0.13	0.18	0.11	0.16
North Pacific									
E	156	154	140	153	150	193	165	169	163
C	144	123	210	156	98	159	154	101	242
CPUE	0.09	0.08	0.15	0.10	0.06	0.08	0.09	0.06	0.15
South Pacific									
E	109	131	81.2	92.2	104	70.6	71.0	70.1	67.7
C	59	49	28	29	30	17	14	14	32
CPUE	0.05	0.04	0.03	0.03	0.03	0.02	0.02	0.02	0.05
Eastern Pacific (E of 130°W)									
E	24.7	52.1	62.0	43.6	47.5	42.4	50.4	67.2	52.1
C	84	166	270	236	223	230	338	208	177
CPUE	0.34	0.32	0.44	0.54	0.47	0.54	0.67	0.31	0.34

[1] E = Effort in hooks $\times 10^6$.
[2] C = Catch $\times 10^3$.
[3] CPUE = Catch/100 hooks.

regions of the Pacific and Indian oceans are examined in section 5.41.

Seasonal variations in available stock are marked. See 2.22 on differential distribution. Kume and Joseph (1969a) have shown that there is a threefold seasonal fluctuation in CPUE for the various regions in the eastern Pacific.

4.23 Average density

No data.

4.24 Changes in density

No data.

4.3 Natality and Recruitment

4.31 Reproduction rates

Annual egg production rates have not been estimated. Little is known of fecundity relationship with fish size. See 3.15 for some estimates.

Nothing is known of survival rates of eggs and larvae because they are so rarely collected.

4.32 Factors affecting reproduction

No data.

4.33 Recruitment

There is little information pertaining to the variation in annual recruitment (see 3.43 and 4.24).

4.4 Mortality and Morbidity

No work has been done on mortality rates or causes of mortality.

4.5 Dynamics of Population (as a Whole)

No work has been done.

4.6 The Population in the Community and the Ecosystem

There is no specific information on this subject available; some general information on distribution and life history is presented in sections 2 and 3.

5 EXPLOITATION

5.1 Fishing Equipment

5.11 Gear

Virtually all of the commercial catch of striped marlin is by longlining. The harpoon fishery for billfishes is responsible for less than 5% of the total catch.

The longline gear aims largely at tunas and billfishes which are distributed at depths of around 100-150 m. The gear consists of mainline, float lines, branch lines, hooks, and buoys. The construction of the longline gear differs according to the species of fish sought, but Morita (1969) presents an example of a "standard" gear (Table 6). Several hundred of these units (each unit is referred to as a "basket") are joined in a series to make up a set. The gear is retrieved with a longline hauler.

Suda and Schaefer (1965) gave examples of the various types of longline gear presently in use (Table 7), and indicated that types 1 through 5 are the more typical ones in use. They also included the estimated hook depths for the different types of gear.

Billfishes are generally found closer to the sea surface than tunas. Therefore, in fishing primarily for billfishes, the longline gear is modified by shortening the float line and the branch lines and also by adding another buoy in the middle of the mainline section, the latter bringing the hooks closer to the surface. Furukawa et al. (1957) reported that for fishing billfishes in the East China Sea, the combined length

Table 6.—General form of tuna longline. (From Morita, 1969.)

Name of part	Material	Length	Number used for 1 basket
Mainline	Cremona (20S, 55×3×3)	250 m[1]	1
Branch line	Cremona (20S, 55×3×3)	11 m	4
Sekiyama	Steel wire (27 # 3×3) and hemp yarn coiled with thread No. 5)	5.5 m	4
Kanayama	Steel wire (27 #, 3×3, Type M)	3 m	4
Hook	Steel	3.8 sun[2]	4
Float Line	Cremona (20S, 55×3×3)	22 m	1
Flag buoy	Flag, bamboo, float (glass ball or synthetic resin ball)	—	1
Radio buoy			2 or 3 (for all basket)

[1] Length per one basket.

[2] 1 sun = 3.03 cm.

Table 7.—Some examples of Japanese tuna longline gear. (From Suda and Schaefer, 1965.)

Type no.	1	2	3	4	5	6	7	8
A. The structure of one basket of the line (unit of length: meters)								
Length of mainline	300	300	300	300	300	245	360	350
Length of branch line								
Cotton or vinyl rope	13.5	10.5	12.0	11.5	12.0	12.0	14.5	12.0
Ganged wire leader	6.0	6.0	8.0	6.0	7.0	8.0	7.0	7.0
Wire leader	1.5	2.0	2.5	1.5	2.0	2.0	3.5	2.5
Length of float line	18.5	19.5	20.0	16.5	22.0	18.0	22.5	25.0
Number of hooks	5	5	5	5	5	4	4	6
B. The estimated maximum depth of each hook of the lines shown above								
No. 1 hook	86.5	85.0	89.5	82.5	90.0	84.5	113.5	92.5
2	127.5	126.0	130.5	123.5	131.0	123.0	169.5	136.5
3	148.5	147.0	151.5	144.5	152.0	123.0	169.5	168.5
4	127.5	126.0	130.5	123.5	131.0	84.5	113.5	168.5
5	86.5	85.0	89.5	82.5	90.0			136.5
6								92.5

of the float line and branch line should not exceed 30 m.

As for the amount of gear fished per day, Yoshida (1966) reported that "Vessels of 39 to 99 gross tons fish 210 to 355 baskets; vessels 100 to 190 gross tons fish 355 to 400 baskets; and vessels 200 to 500 tons fish 400 to 450 baskets." Suda and Schaefer (1965) reported that Japanese vessels in the eastern Pacific fished an average of 2,000 hooks (about 400 baskets) per set.

The basic construction of the longline gear has remained unchanged over the years. However, due to manpower problems some effort has been directed towards developing laborsaving devices in longlining. Two examples are the reel-type and tub-type of longlining.

In the reel-type, the mainline is continuously reeled onto a drum, while in the tub-type, the retrieved line is coiled into a large tub. Important advances in addition to the line hauler, include the "slow-conveyor" (for line setting and line hauling), the "guide stand" and "guide roller" (for leading line), gear-transporting conveyor system, line-winder system, etc. In using these methods, the branch lines are joined to the mainline by the use of snaps (Katsuo-Maguro Nenkan, 1969).

The principal bait used in longlining is frozen Pacific saury, *Cololabis saira.* Squid is also commonly used. Mackerel, *Scomber* sp., as well as mackerel scad, *Decapterus* sp., have been used as alternate bait. In addition, experiments are underway to utilize silver carp, *Hypophthalmichthys molitrix*, as well as artifical preparations (e.g., infused with extracts of saury) as longline bait.

Depending on the location, certain baits have been reported to have advantages in catching billfishes. For instance, in the East China Sea fishing grounds, live mackerel were believed effective and were used extensively. However, Furukawa et al. (1957) reported that using live or dead mackerel did not significantly affect the catches of white marlin (= black marlin), striped marlin, and broadbill.

The main piece of equipment in the harpoon fishery is the harpoon itself. The harpoon pole of oak is about 4 m long and at its tip is a three-pronged iron piece about 7 mm in diameter. The detachable harpoon of steel about 10 cm in length, connected to about 100 m of line, is placed over this iron tip. Recently the electric harpoon has been used in order to kill the fish quickly. When the harpoon enters the fish, a wire distributed along the harpoon line is charged with electricity.

5.12 Boats

The longline vessels fishing in the Indian and Pacific oceans for striped marlin are largely those from Japan. Other vessels are from Taiwan and Korea.

The details on the construction of longline vessels are given by Kanasashi (1960) and by Yoshida (1966). There are two types of longline vessels: those that use longline exclusively and those that use both longline and pole and line. The holds on longline vessels are not divided into small compartments to carry live bait. Thus, the hold space in the longliners is 20% to 40% greater than in the combination vessels.

Longline vessels are constructed of wood or steel; those larger than 100 gross tons are usually constructed of steel. Most of the longliners are 250 to 350 gross tons; at this stage of the fishery they appear to be the most economical and efficient size to operate. The specifications of typical longliners of this size class and those of some typical combination vessels are given in Yoshida (1966).

Other than the independently operating vessels, there is the mother ship operation in which several catcher boats are transported on the deck of a mother ship to the fishing grounds.

Small mother ships of 400 to 800 gross tons are able to carry only one portable catcher boat, but the larger 2,000- to 3,000-ton mother ships carry six catcher boats. The portable catcher boats measure about 15 m in length (Yoshida, 1966). To decrease the weight of the portable boats, recent constructions have been of fiber-reinforced plastic (FRP). The weight of a FRP boat is about 13 tons, or approximately two-thirds the weight of former catcher boats (Kazama, 1967).

Significant advances have also been made in preserving the catch of high-quality sashimi fish. Many vessels are equipped with refrigeration equipment capable of preserving the catch at very low temperatures of −40° to −45°C. In this way, the vessels are able to deliver fish in excellent condition and as a result, billfish prices have increased greatly in the Japanese market.

In addition, there have been advances in automating ship operations, fishing gear, and other equipment. Almost all longliners are equipped with fish detectors. Living conditions on the ships have also been improved considerably, and many vessels are now equipped with air conditioning for the crew's comfort (Katsuo-Maguro Nenkan, 1969).

Harpoon vessels are constructed with an extended prow where the harpooner is stationed. These vessels are constructed of wood, and range in size from about 10 to 40 tons. Billfishes taken by these vessels are kept in ice for delivery to the market.

5.2 Fishing Areas

5.21 General geographic distribution

The longline fishery now virtually covers the entire distribution of the species (see 2.1 and 2.22). The major sport fishing areas are southern California, Mexico, Panama, Ecuador, Peru, Chile, Hawaii, Tahiti, Fiji, New Zealand, Australia, and East Africa (not listed in order of importance).

5.22 Geographic ranges

See also 5.41.

Longlining is carried out across the high seas to within 5 miles of coastlines in places. The sport fishery is generally restricted to within about 75 miles of coastlines with the bulk of the fishing much closer.

The greatest fishing pressure is exerted in the North Equatorial Current in the Pacific and western Indian oceans, in the Kuroshio and Kuroshio extension, in the North Pacific Gyral northeast of the Hawaiian Islands, in the South Equatorial Current from about long. 90° to 140°W, and also off Mexico and Ecuador.

Regarding the development of the Japanese longline fishery, Suda and Schaefer (1965) report that prior to about 1952 the fishery was confined to the western and central Pacific. After this date it expanded into the Indian Ocean extending west of long. 80°E in 1954 and throughout the Indian Ocean by the end of 1955. In the Pacific, the fishery expanded eastward between lat. 10°N and lat. 10°S reaching 130°W by late 1956 and long. 85°W by 1961. After 1963 the fishery in the eastern Pacific expanded rapidly poleward, the northward expansion being primarily for striped marlin (Kume and Joseph, 1969a).

The fishing grounds for the Japanese harpoon fishery are located in the waters of Sanriku (off northeast of Honshu), around Izu, and East China Sea.

5.23 Depth range

Little has been written regarding fishing effort by depth range. Merrett (1968a) reports almost half of the striped marlin caught during experimental longlining off East Africa were caught over less than 1,000 fathoms even though most of the effort was expended beyond this depth contour.

5.24 Conditions of the grounds

See sections 2.1, 2.2, and 2.3.

5.3 Fishing Seasons

For sections 5.31, 5.32, and 5.33 see section 2.22.

The fishing season for the Japanese harpoon fishery in the waters of the Sanriku fishing ground extends from June to November with the peak occurring from July through September; in the Izu area from December to August with its peak from February through April; and in the East China Sea from December to February.

5.4 Fishing Operations and Results

5.41 Effort and intensity

Type of unit of effort: Detailed data on fishing effort and catch in the Japanese tuna longline fishery are published in the "Annual report of effort and catch statistics by area on Japanese tuna longline fishery" by the Research Division, Fisheries Agency of Japan. Fishing effort is reported in terms of number of operations and number of hooks fished; catch is reported in terms of number of fish. The statistics are reported on a monthly basis by 5° units.

Since 1967, Taiwan has also begun to publish data from their tuna longline fishery, following the same format as the Japanese publication. The Taiwan data are published annually in "Report on survey of production and marketing of Taiwan's tuna longline fishery" by the Taiwan Fisheries Bureau. Publication of effort and catch statistics of the Korean longline fishery started in 1970 in "Yearbook of catch and effort statistics on Korean tuna longline fishery" issued by the Office of Fisheries, Korea.

Landings per unit of fishing effort: As noted above, the catch statistics are reported in terms of numbers of fish taken in the various unit areas. Landings by weight can be estimated from the data along with average body weight data.

Catches per unit of fishing effort: The catch per unit of effort (CPUE) can be obtained in terms of catch in numbers per 100 or 1,000 hooks fished. Strasburg (1970) studied year-to-year changes in CPUE of billfishes in the Pacific by analyzing the 1953-63 Japanese longline data for quadrangles measuring 20° of latitude and longitude. He noted a progressive decline over the years in the CPUE for the striped marlin of western and central South Pacific (lat. 20°-40°S) areas. Strasburg (1970) concluded that while some workers have attributed the decline in CPUE to heavy fishing, "It is impossible to determine its real cause without more information on various biological features related to migration, reproduction, age, and year classes."

Honma and Suzuki (1969) studied the apparent abundance of striped marlin in the principal fishing grounds in the Pacific (northwestern Pacific, eastern Pacific, and waters east of Australia) for the years 1960-66. They noted no apparent trends in CPUE in the northwestern Pacific and eastern Pacific grounds. On the other hand, for waters east of Australia, they reported a definite decreasing trend; the CPUE has been at a low level of around 0.1 fish per 100 hooks since 1964.

Of the striped marlin in the Indian Ocean, Kikawa et al. (1969) examined the annual changes in CPUE (number of fish per 1,000 hooks) based on data for the years 1962-67. They reported CPUE of about 0.6 fish per 1,000 hooks between 1962 and 1964, followed by an increase to about 1.0 in 1965-67. The authors concluded that "An increasing trend in the CPUE for striped marlin in this period may probably represent the increase in effectiveness in catching fish."

Fishing effort per unit area: Figure 8 shows the distribution of fishing effort of the Japanese tuna longline vessels in 1970. The effort, in terms of numbers of hooks fished, is shown by 5° quadrangles.

If we examine the data along with catch per unit area data of striped marlin (Fig. 9) it is apparent that the relatively large fishing effort in the eastern Pacific off Mexico and Ecuador is principally related to pursuit of striped marlin in those areas.

Total fishing intensity: The total fishing effort of the Japanese longline vessels in recent years (1965-69) for the Pacific and Indian oceans is estimated at about 400 million hooks fished per year. The efforts by areas are given in Table 5 (see 4.23).

Since 1963 there has been a significant increase in fishing effort in the eastern Pacific region. Correspondingly the fishing grounds for striped marlin also has increased during this period.

In the South Pacific region, however, effort has decreased from about 100 millin hooks in 1965-66 to around 70 million hooks beginning in 1967.

5.42 Selectivity

Small striped marlin under 80 cm eye-fork length are virtually never taken by longline.

Furukawa et al. (1958) have reported that striped marlin taken by harpooning in the East China Sea fishing grounds are relatively heavier (higher fatness index) than fish taken by longline.

5.43 Catches

Total annual yields: The FAO "Yearbook of fishery statistics" reports the total annual yields of striped marlin; Table 8 summarizes the 1970 catch (FAO, 1971). The recent total annual landings of striped marlin have been around 25,000 tons from the Pacific and Indian oceans.

Total annual yields from different fishing grounds: As seen in Table 8, the striped marlin catches are high in the eastern Pacific; the catch from this area comprises about one-half of the total Pacific

Table 8.—Catches of striped marlin by fishing areas for 1964-70. (From FAO, 1971.)

Area	1964	1965	1966	1967	1968	1969	1970
	In thousands of metric tons						
Indian Ocean	(2.4)	(3.8)	(3.8)	(6.2)	(3.8)	(4.3)	(3.1)
Western	1.2	2.1	3.2	4.9	2.2	2.5	2.1
Eastern	1.2	1.7	0.6	1.3	1.6	1.8	1.0
Pacific Ocean	(25.6)	(22.5)	(20.5)	(19.5)	(21.6)	(20.5)	(22.1)
Northwest	8.6	8.8	7.0	6.9	7.2	8.5	8.4
Eastern central	14.0	11.3	9.1	10.4	11.0	8.7	10.9
Southwest	1.4	1.3	2.3	0.9	1.7	1.6	1.6
Southeast	1.6	1.1	2.1	1.3	1.7	1.7	1.2
Total	28.0	26.3	24.3	25.7	25.4	24.8	25.2

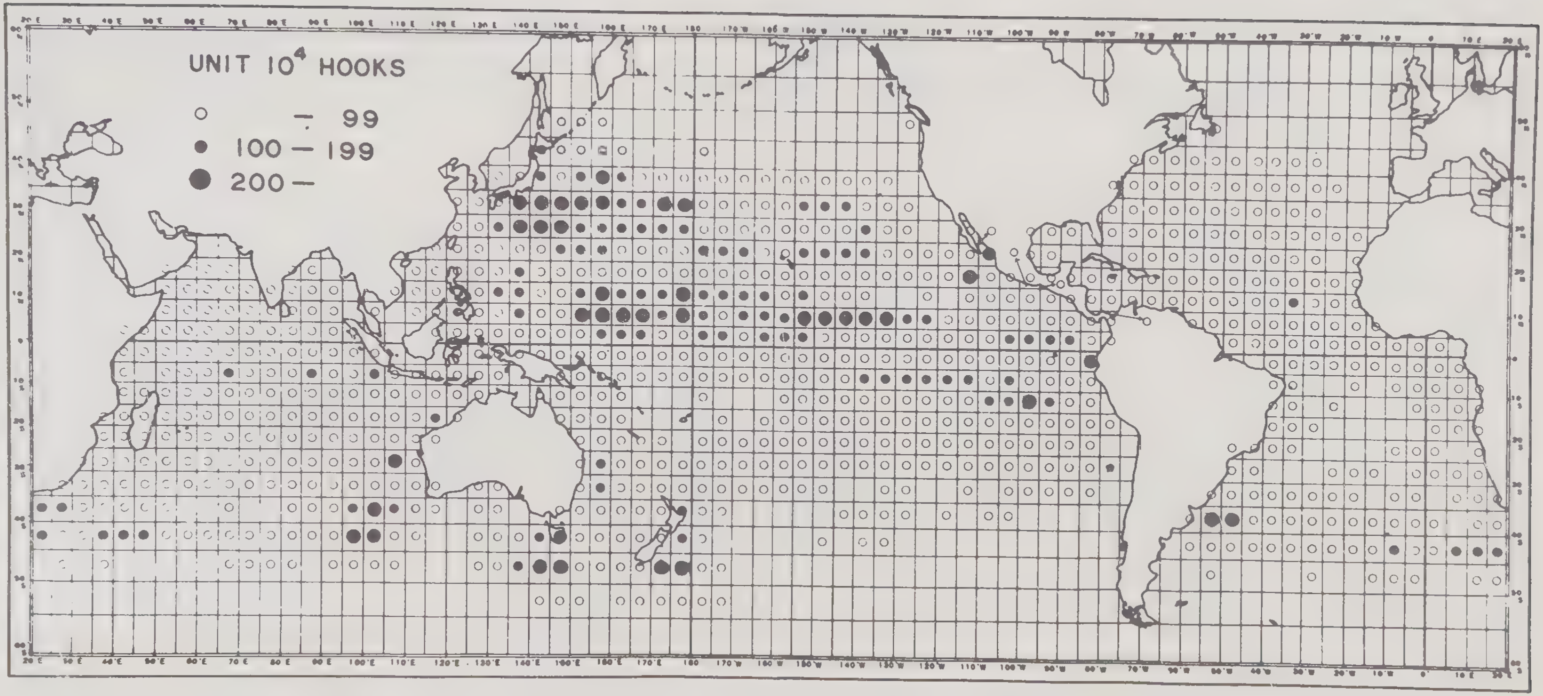
UNIT 10⁴ HOOKS
○ — 99
● 100 — 199
● 200 —

Figure 8.—Distribution of estimated total fishing effort, in numbers of hooks per unit area (1970).

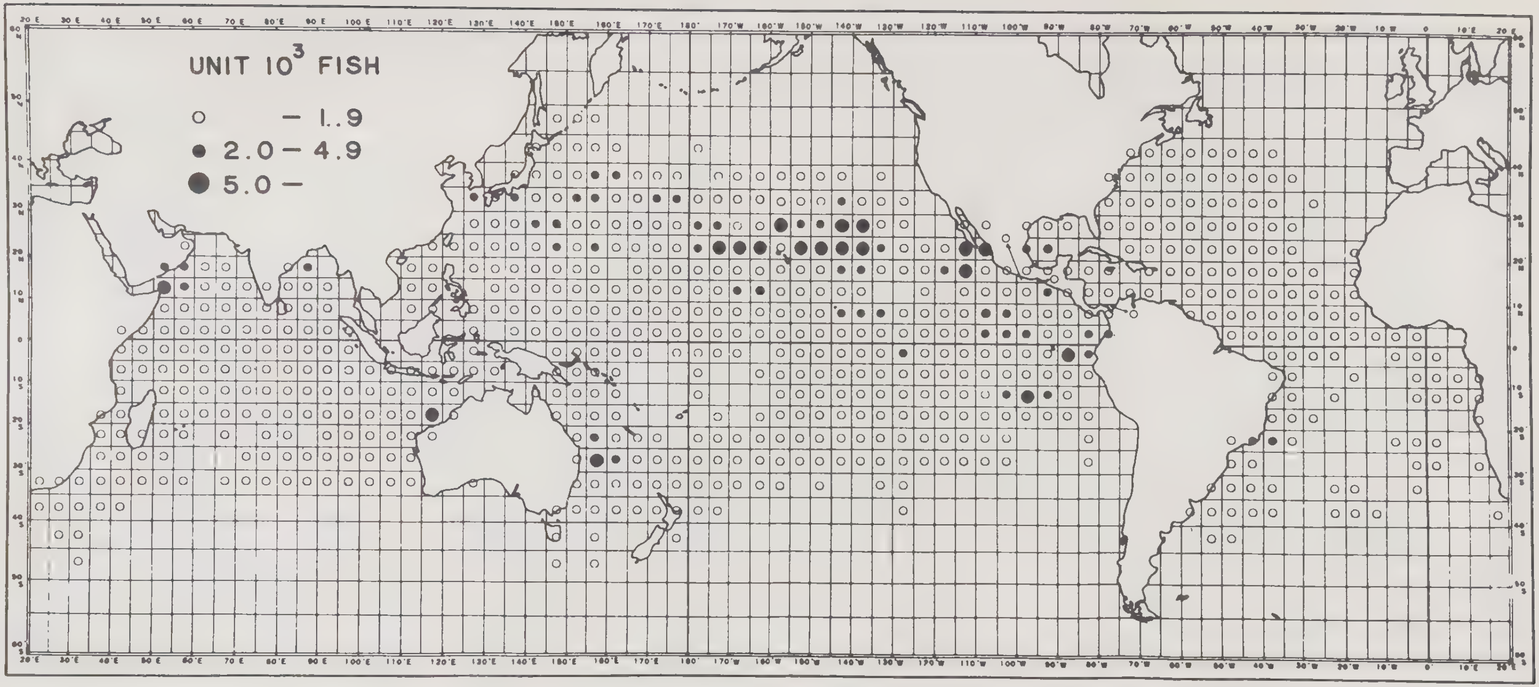
UNIT 10³ FISH
○ — 1.9
● 2.0 — 4.9
● 5.0 —

Figure 9.—Distribution of the catch of striped marlin in numbers per unit area (1970). Catch data in Atlantic Ocean area pertains to white marlin, *Tetrapturus albidus*.

landings. The Indian Ocean landings of striped marlin amount to approximately 20% of the Pacific landings.

Maximum equilibrium yield: Honma and Suzuki (1969) made some preliminary determinations of the maximum sustainable yield on the basis of 1960-66 data. They suggested that striped marlin catches in the Pacific can probably be increased about 60% over the recent average annual landings.

However, judging by the fact that catches have leveled off in recent years after fishing effort has virtually covered all of the known areas of striped marlin distribution, it appears that the present catches may be close to the maximum equilibrium yield level.

Obviously, further research is needed on this subject.

6 PROTECTION AND MANAGEMENT

6.1 Regulatory (Legislative) Measures

6.11 Limitation on reduction of total catch

The Japanese tuna longline fishery is regulated in terms of fleet size by the vessel licensing system. Licensing is reviewed at 5-yr intervals and fleet size is governed on the basis of the condition of the tuna resources. No increase in fleet size has been permitted since 1963. However, other countries such as Korea and Taiwan have increased the size of their longline fleet.

7 POND FISH CULTURE

Not applicable.

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On the Development of Blocking Ridge Activity Over the Central North Pacific

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ABSTRACT

Monthly mean atmospheric data taken over the North Pacific during the period 1950–70 are used to investigate blocking ridge activity over the central ocean. The blocking ridge is observed to be a finite-amplitude, quasi-stationary long wave, most often centered over the North Pacific at 170W, superimposed upon the quasi-zonal mid-latitude westerlies. The dominant length scale is 7000 km, the same dimensions as the width of the mid-latitude ocean. The growth time scale is 1–2 weeks, with the duration of blocking activity rarely exceeding 2 months in any given year. The blocking activity is confined almost exclusively to the autumn/winter months, where block development is closely coupled with the sensible heat transfer from the underlying ocean (anomalously small heat transfer under the ridge and anomalously large heat transfer under the associated troughs). Year-to-year variability in blocking ridge activity is found to have a dominant time scale of approximately 5 years from 1950–70 and to be inversely correlated (−0.79) with the strength of the autumn/winter mean mid-latitude westerlies (the mean formed using months not containing blocking activity). Further analysis shows that both blocking ridge activity and the strength of the westerly winds fluctuate together with the Southern Oscillation over this time period.

These space/time scale considerations suggest that this regional blocking activity owes its existence to the marine environment. To test this idea, appeal is made to some theoretical work by Haltiner, where the baroclinic instability process was modified by sensible heat transfer from the ocean to the atmosphere. Haltiner found that for normal winter values of the background flow, the otherwise stable stationary long wave became unstable when sensible heat transfer was allowed. The wavelength for the unstable stationary wave was 7000–8000 km with a growth time scale of approximately 2 weeks. The scales are similar to that of blocking ridge activity over the North Pacific.

In addition to good scale agreement with observations, Haltiner's theory is able to explain both the seasonal and year-to-year variability in blocking activity in terms of corresponding fluctuations in sensible heat transfer and the strength of the mean westerly winds.

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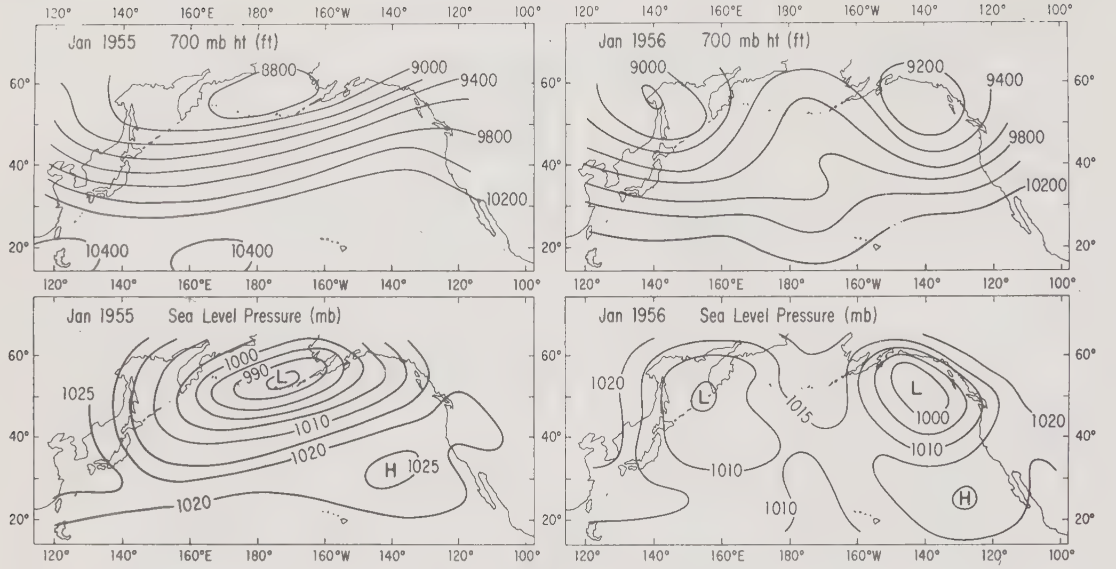
1. Introduction

For 25 years a central problem in long-range weather forecasting over North America has been understanding how blocking ridges develop over the central North Pacific Ocean. When blocking occurs, the passage of synoptic storms across the ocean is interrupted, and the storm paths over the North American continent are altered. This, of course, has an important influence upon the weather experienced there.

It has long been recognized (e.g., Rex, 1951) that the mid-latitude westerlies over the North Pacific exist in either one of two quasi-stationary wave states: one associated with primarily zonal motion and the other characterized by meridional motion (i.e., blocking situations). Typical winter monthly mean maps of 700 mb height over the North Pacific are displayed in Fig. 1. The wave state associated with primarily zonal motion is found most frequently and is characterized by that of January 1955 with a trough off the east coast of Asia and a ridge over the west coast of North America. The wave state associated with blocking ridge development is found less frequently and is characterized by that of January 1956 with a ridge over the central ocean near 170W and troughs at the ocean's perimeter, resulting in a typical wavelength of ~7000 km. Comparing these maps to the long-term mean map of 700 mb height for the month of January (Fig. 2) shows that the blocking ridge is a finite-amplitude wave perturbation to the quasi-zonal mean flow. When blocking activity is absent, the flow configuration is much like the mean state. Therefore, the blocking ridge seems to be a quasi-stationary instability of some kind, whose presence or absence may depend upon characteristics in the annual mean zonal flow over the mid-latitude North Pacific.

Reasons for development of the mean wave state have been known for some time. Smagorinski (1953) has investigated the influence of large-scale heat sources and sinks upon the zonal mid-latitude westerlies utilizing a thermally active, stationary perturbation model of the atmosphere. In his model, heat sources represent the oceans during winter, and heat sinks represent the


Jan 1955 700 mb ht (ft)
8800
9000
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Jan 1956 700 mb ht (ft)
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9800
10200
Jan 1955 Sea Level Pressure (mb)
1000
990
L
1010
1020
1025
H 1025
1020
Jan 1956 Sea Level Pressure (mb)
1020
L
1015
L
1000
1020
1010
1010
1010
H
120°
140°
160°E
180°
160°W
140°
120°
100°
60°
40°
20°

Fig. 1. Monthly mean maps of 700 mb height and sea level pressure over the North Pacific for January 1955 and January 1956.

continents. He was able to show that the present distribution of continental heat sinks and oceanic heat sources in the Northern Hemisphere were responsible (together with continental orographic effects) for the development of the mean quasi-stationary long waves that are observed (Fig. 2), i.e., ridges over the continents and troughs over the oceans with the latter intensified off the east coast of continents. In addition,

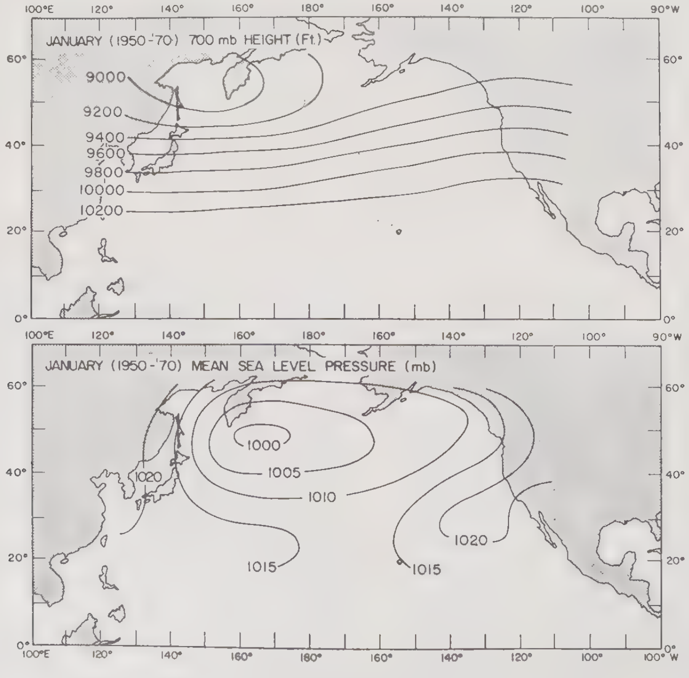
JANUARY (1950-'70) 700 mb HEIGHT (Ft.)
9000
9200
9400
9600
9800
10000
10200
JANUARY (1950-'70) MEAN SEA LEVEL PRESSURE (mb)
1000
1005
1010
1020
1015
1020
1015
100°E
120°
140°
160°
180°
160°
140°
120°
100°
90°W
60°
40°
20°
0°

Fig. 2. Long-term (1950–70) monthly mean maps of 700 mb height and sea level pressure for January.

he shows the upper-level troughs and ridges to be in phase with the heat sources and sinks, respectively, whereas the associated low-level pressure systems are displaced one-quarter wavelength downstream (Fig. 2).

The reasons for development of the mid-ocean blocking ridge are not yet known. Various investigators have tried to understand the mechanisms responsible for blocking activity, but with limited success. In an early study, Namias (1950) postulated that the blocking ridge occurred in response to a buildup of cold air over the polar regions that was contained by strong mid-tropospheric westerlies. The formation of the block acted to discharge this cold air into subtropical regions, thereby maintaining a balance between heat gain at the equator and heat loss at the poles. This is equivalent to saying that the blocking ridge is a manifestation of baroclinic instability. At about this same time, Rex (1951) suggested that block development was analogous to a hydraulic jump in open channel flow. More recently, Bjerknes (1969) observed that blocking ridges tended to form when the autumn/winter mid-latitude westerlies were weaker than normal and hypothesized that they were shorter stationary Rossby waves. However, this explanation, like that of Rex, lacks a feasible energy source required to excite this quasi-stationary wave state.

From a different point of view, Namias (1959) hypothesized that the mid-ocean blocking ridge could be a fundamental unstable mode of the coupled ocean/atmosphere interacting system which derives its energy from thermal energy anomalies contained in the upper ocean. However, it seems clear from the work of Clark (1967) and Kraus and Morrison (1966) that the fluctuating ocean temperature does not necessarily play an active role in thermal energy exchange on time scales less than a year. Furthermore, mid-ocean blocking ridge development has been duplicated in numerical simulations of the January climatic state (e.g., Mintz, 1968; Rountree, 1972) by treating the ocean as a passive infinite heat source that gives up thermal energy to the atmosphere on demand.

In the present study, we expand the theoretical idea suggested by Namias (1950) and show that blocking ridges can result through the mechanism of baroclinic instability, but only in the presence of sensible heat transfer from the ocean to the atmosphere. This accounts for the presence of blocking ridge activity over the central North Pacific. In the absence of sensible heat transfer, baroclinically unstable stationary wave growth is not possible, except at unrealistically high values of the thermal wind. However, Haltiner (1967) has shown that with sensible heating from the ocean, which is treated as an infinite heat source, both stationary and retrograde waves can grow in amplitude for normal values of the thermal wind. The time and length scales of these unstable stationary waves are narrowly defined but are the same as those observed in mid-ocean blocking ridge development.

Because mid-ocean blocking ridges can be interpreted as baroclinically unstable waves, seasonal and year-to-year differences in blocking activity may be associated with changes in the characteristics of the annual mean mid-latitude westerlies and the sensible heat exchange over the North Pacific. This is clearly demonstrated in the subsequent development.

2. Blocking ridge defined

Before proceeding further, we need to define what is meant by the term "blocking ridge." In the past, this term has had different interpretations. The best definition seems to have been given by Rex (1951), who cataloged blocking ridge activity over both the North Pacific and North Atlantic from 1933–50. He gave the following definitions (slightly paraphrased):

1) A sharp transition in the westerlies from a zonal type upstream to a meridional type downstream must be observed.

2) The basic westerly current must split into two branches, each transporting appreciable mass.

3) This double jet must extend for more than 45 degrees of longitude and last for greater than 10 days.

Upon inspection of Fig. 1 for January 1956, it is clear that this wave pattern meets all of the criteria listed above. As such, it can be considered an example of a classical blocking situation.

Whereas Rex determined blocking ridge activity from a study of Northern Hemisphere synoptic weather maps, we plan to investigate blocking ridge activity using Northern Hemisphere monthly mean maps (prepared by the Long Range Prediction Group of the National Weather Service). As such, we are not able to determine the growth time of a blocking situation as Rex was able to do; we are able only to determine that it existed for enough time to dominate the monthly mean pressure pattern.

Upon inspection of the monthly mean maps, we found in most cases, when part 1) of Rex's definition was found, that 2) was also satisfied. However, we also discovered many cases where this was not true; a sharp transition in the westerlies from a zonal type upstream to a meridional type downstream was not always associated with a splitting of the westerly current, as for example in Fig. 3. Yet, clearly this wave state represents a block to the eastward passage of storms. Thus, we have altered Rex's definition of a blocking ridge to include waves of the type shown in Fig. 3. In addition we have specified that the amplitude of these waves must exceed 5° of latitude. The definition for our present use reads:

A blocking ridge exists when a sharp transition in the mid-latitude westerlies from a zonal type upstream to a meridional type downstream occurs with an amplitude exceeding 5° of latitude.

We emphasize that we are designating blocking ridge development over the North Pacific and excluding

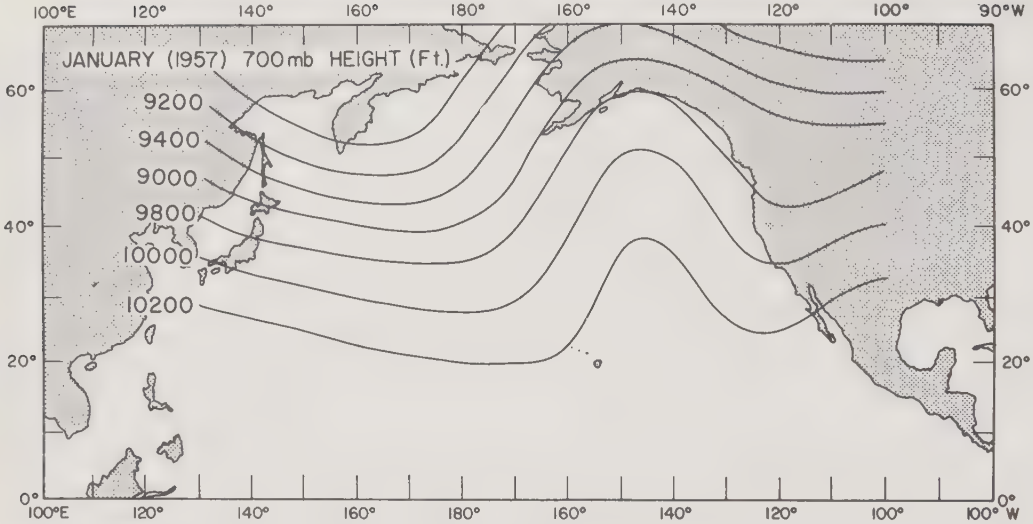

Fig. 3. Monthly mean map of 700 mb height over North Pacific for January 1957.

those that develop over the western part of North America, which seem to be amplified mountain waves.

3. Time scales of blocking ridge activity

The month of occurrence and month-to-month persistence of blocking ridge activity over the central North Pacific can be seen from a tabulation of this phenomenon during the period 1950–70 (Table 1). In this table, the black squares designate months in which blocking ridges formed over the central North Pacific (as defined in the previous section); hatched squares designate months that had ridges over the central North Pacific whose amplitudes were less than 5° of latitude; and the blank squares designate months when no ridging occurred over the central North Pacific.

Inspection of this table shows that blocking ridge activity was intermittent from year to year, occurring more often in winter than in summer. In general, blocking ridge activity appears to have had an average period of existence of one or two months; it lasted for three consecutive months in only one year, 1955–56. When blocking occurred in two or more months of any given year, it occurred most often in consecutive months rather than in separate ones.

The seasonal variability of blocking ridge development can be seen in the histogram (Fig. 4) constructed

Table 1. The occurrence of blocking ridge activity (black squares) and of modified ridging activity (hatched squares) over the central North Pacific during the months of each year from 1950–70. Blank squares designate no ridging activity (blocking or otherwise) found in the central North Pacific.

■ BLOCKING RIDGE ▨ RIDGE ☐ NO RIDGING

	1950		1952		1954		1956		1958		1960		1962		1964		1966		1968		1970
JAN	■	☐	■	☐	■	☐	■	■	☐	■	☐	☐	■	☐	☐	☐	☐	▨	■	■	☐
	■	▨	☐	☐	☐	☐	▨	■	☐	☐	☐	☐	■	☐	☐	☐	☐	☐	☐	☐	☐
MAR	☐	▨	▨	☐	▨	▨	☐	☐	☐	☐	■	☐	☐	■	☐	■	▨	■	☐	☐	☐
	☐	☐	☐	☐	■	☐	☐	☐	☐	☐	☐	☐	■	☐	▨	▨	☐	■	☐	☐	☐
MAY	☐	☐	▨	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	▨	☐	☐	☐	☐	☐	▨
	☐	☐	▨	■	☐	☐	☐	☐	☐	☐	☐	▨	▨	☐	☐	☐	☐	☐	☐	☐	☐
JUL	☐	☐	☐	☐	☐	☐	☐	■	☐	■	☐	☐	☐	☐	☐	☐	☐	▨	☐	☐	☐
	☐	☐	☐	☐	▨	☐	☐	▨	☐	☐	☐	▨	▨	☐	☐	☐	☐	☐	▨	■	☐
SEP	☐	☐	☐	☐	▨	☐	▨	■	☐	☐	☐	☐	☐	☐	☐	■	☐	☐	☐	☐	☐
	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
NOV	■	☐	☐	☐	☐	■	☐	☐	☐	☐	☐	☐	☐	▨	☐	▨	▨	☐	☐	☐	■
	☐	☐	☐	☐	▨	■	☐	☐	☐	☐	☐	▨	☐	☐	■	☐	☐	■	▨	☐	▨

from data in Table 1. During the period of time from 1950–70, the seasonal maximum occurred in the autumn/winter season (October–March) with an ill-defined minimum in spring/summer. Earlier work by Rex (1951) on the seasonal variability of blocking activity differs somewhat from these results, but this can be traced to his inclusion of mountain blocking activity. We find that blocking activity over the Rocky Mountains is primarily a spring/summer phenomenon and would seriously alter the seasonal variability of North Pacific blocking activity if included.

There is little that we can add to the description of the growth process of blocking ridges due to the inadequate time resolution involved in working with monthly mean maps. In most instances the presence of blocking activity was not preceded by any suggestion of ridging activity in the previous month (see Table 1). Yet, in some instances of blocking activity, the block seems to have been preceded by a slight ridging in the previous month. More importantly, in some of these situations, the ridging preceding the block seems to have occurred east of the blocking location, generally just off the west coast of North America. The resulting block development seems to arise from a westward (i.e., retrograde) motion of this initial ridging phenomenon. For an ex-

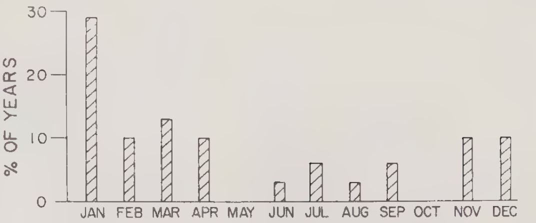

Fig. 4. Histogram based on data in Table 1 displaying the long-term monthly variability of blocking ridge activity from 1950–70 (31 cases).

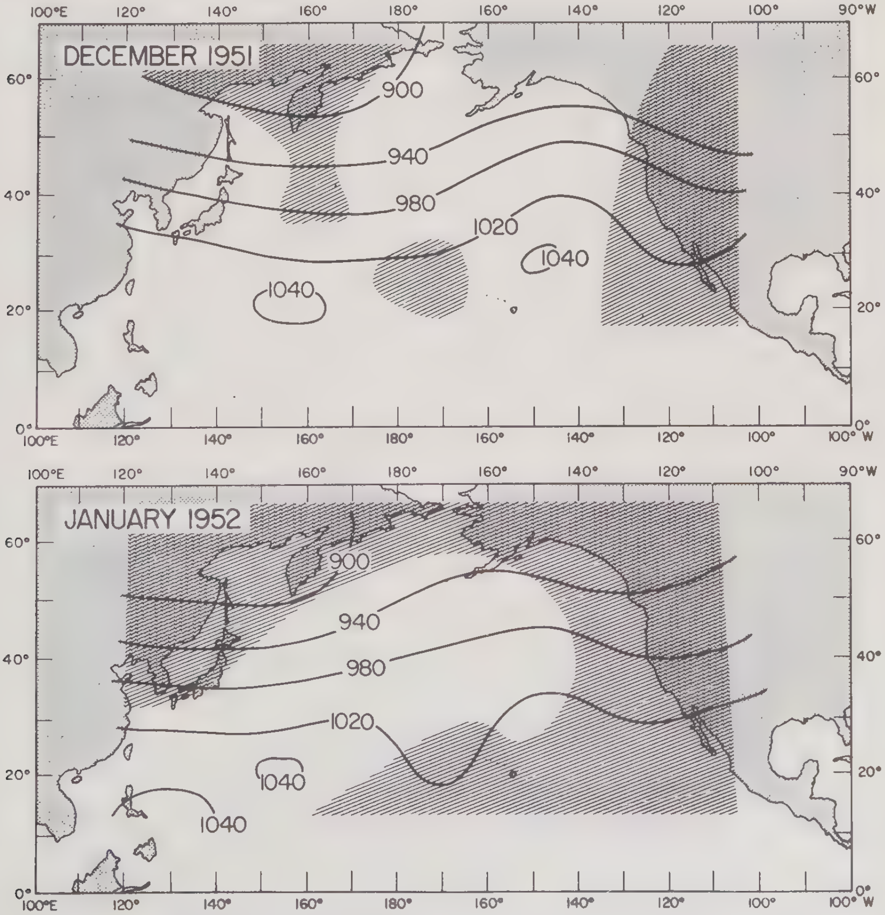

Fig. 5. Monthly mean maps of 700 mb height over the North Pacific for the months of December and January, 1951–52. The background shading indicates regions of negative 700 mb height anomaly.

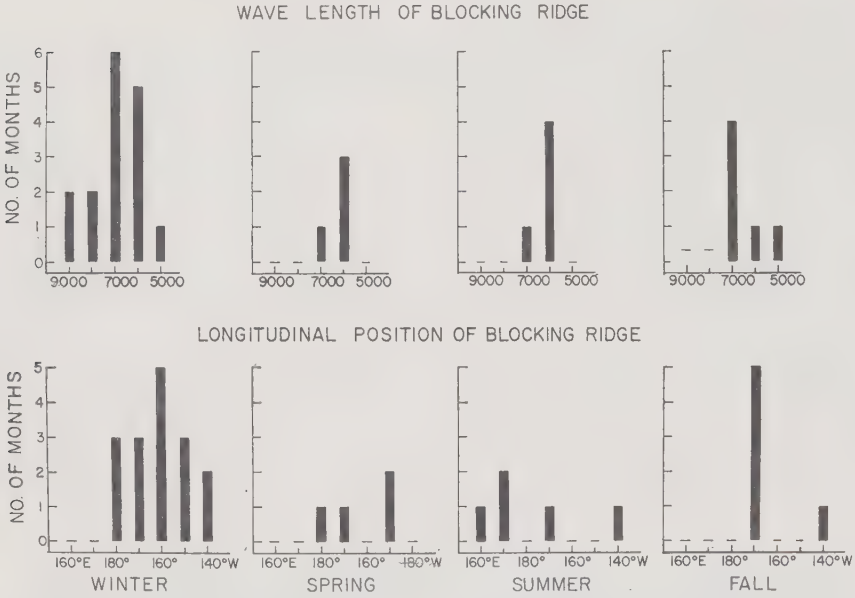

FIG. 6. Histograms based on data in Table 1, displaying the wavelength and longitudinal potition of the blocking ridges, with seasonal resolution.

ample of this, consider Fig. 5 which shows the 700 mb height fields for the months of December 1951 and January 1952 when a blocking ridge was fully developed in January. In 1951, the month of November was nearly normal (not shown), but in December a wide ridge began building off the west coast of North America and extended out over the eastern North Pacific. Then in January 1952 the block occurred over the central ocean, apparently developing from a retrograde displacement of the initial ridging off the west coast of North America.

The time scales of year-to-year variability in blocking ridge activity will be discussed in a separate section.

4. Space scales of blocking ridge activity

In most cases of blocking ridge activity noted in Table 1, the center of the ridge was found at 170W which is the center of the North Pacific at mid-latitudes. Associated with this, the modal wavelength of the blocking ridge (i.e., the distance between the troughs off the east coast of Asia and off the west coast of North America) was found to be ~7000 km, the same dimensions as the width of the North Pacific at mid-latitude.

Seasonal variability of the blocking ridge wavelength is indicated in Fig. 6. In autumn and winter the modal wavelength is clearly 7000 km, while in spring and summer it is 6000 km. A seasonal breakdown in longitudinal position of blocking activity is also indicated. In autumn and winter the modal position of the blocking activity is between 160 and 170W, but during the spring and summer it is ill-defined, with individual blocking situations extending from 160E–140W.

In summary, blocking ridge activity is found most often during the autumn/winter months (October–March), is located at 170W near the center of the North Pacific, and has a wavelength (7000 km) that is the same as the zonal dimensions of the mid-latitude ocean. These results provide a basis for the hypothesis that blocking ridge activity owes its existence to the underlying ocean environment. The next section explores this possibility.

5. Sensible heating and blocking ridge activity

Mid-ocean blocking ridge activity occurs during the autumn and winter months (Fig. 4) when the maximum heat transfer from the ocean to the atmosphere takes place (Clark, 1967). Therefore, because the blocking ridge also develops near the center of the North Pacific, it is reasonable to suggest that the local sensible heat transfer from the sea surface, Q_s, may be important in its development.

First, consider some individual months where the anomalous sensible heat flux field (taken from Clark, 1967) is compared with the anomaly of 700 mb height associated with mid-ocean blocking ridge activity. Fig. 7 shows these anomalous fields from November 1956 to January 1957. Note that the anomalous ridging associated with the growth of the blocking ridge is associated with anomalously low sensible heat transfer at the surface. Alternately, anomalous troughing is

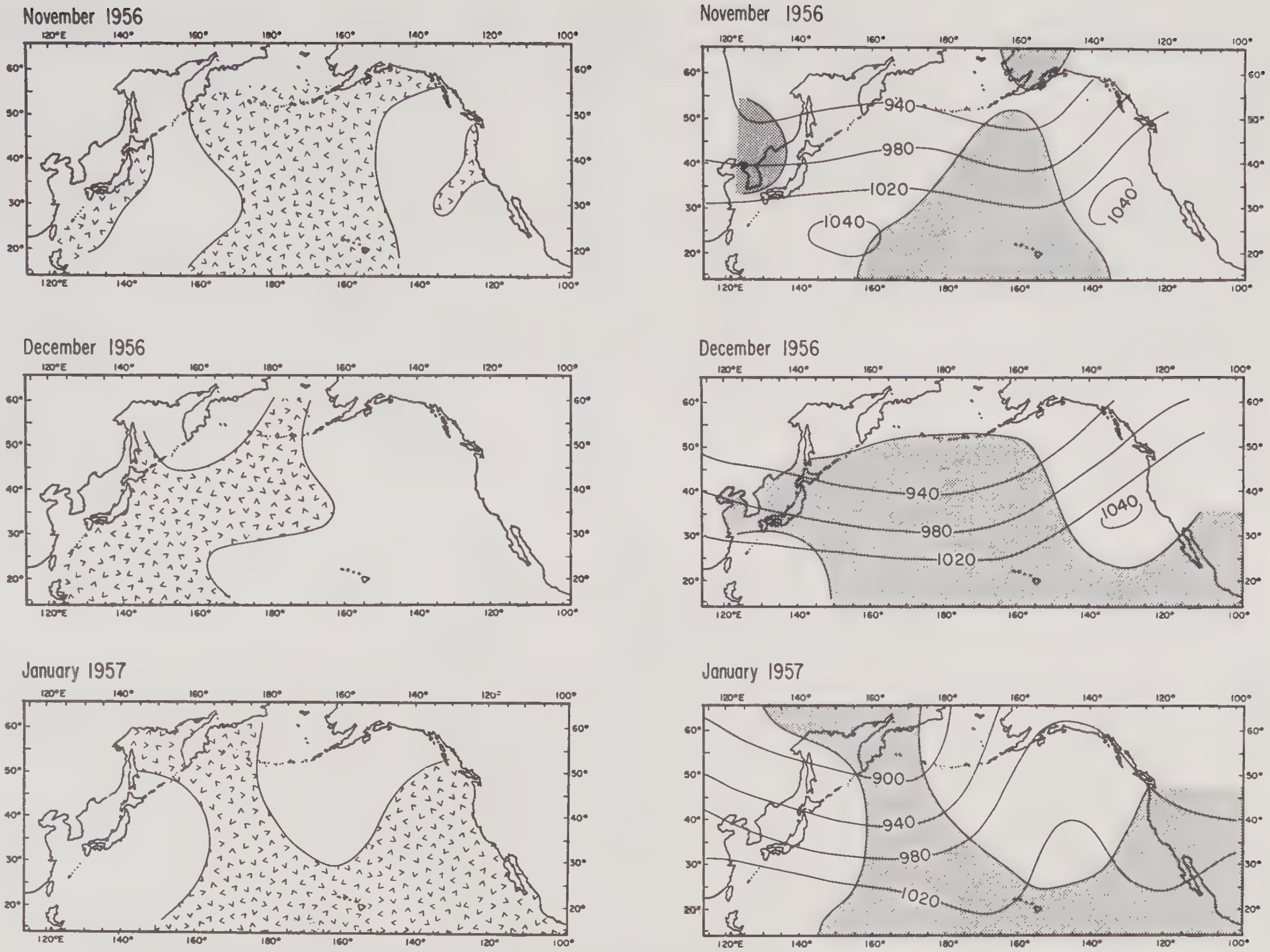
November 1956
November 1956
December 1956
December 1956
January 1957
January 1957
120°E
140°
160°
180°
160°
140°
120°
100°
60°
50°
40°
30°
20°
940
980
1020
1040
1040
900

Fig. 7. The sensible heat flux anomaly Q_s (left) and 700 mb height anomaly (right) for the months of November, December and January of 1956–57. The mean in this case was taken over the period 1951–57, the time period over which heat flux information was available (Clark, 1967). In the left-hand panels, patterned areas designate anomalously high sensible heat flux; in the right-hand panels, shading designates anomalously low 700 mb height.

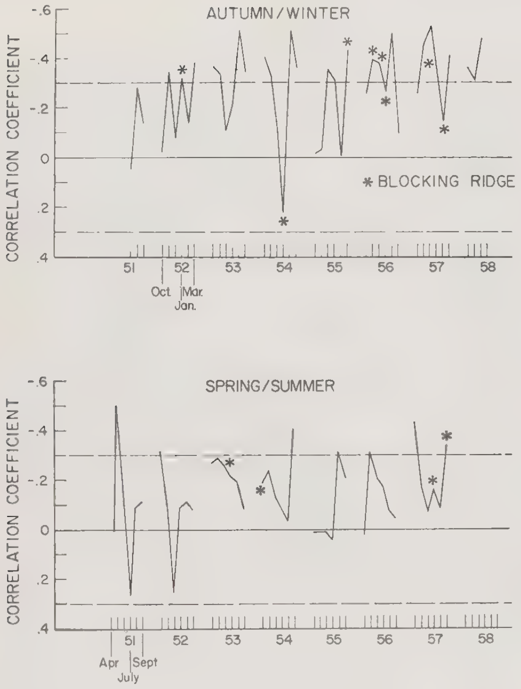

FIG. 8. The time sequence of pattern correlation between anomalous sensible heat exchange (taken from Clark, 1967) and 700 mb height anomaly over the North Pacific from 20–55N: upper panel, autumn/winter months (October–March); lower panel, spring/summer months (April–September).

associated with anomalously high sensible heat transfer at the surface. Pattern correlations between anomalies of Q_s and 700 mb height fields for these three months are −0.46, −0.52 and −0.36, respectively.

Pattern correlations between anomalous sensible heat exchange and anomalous 700 mb heights for other years are plotted in Fig. 8. The upper panel of Fig. 8 displays the correlation coefficients for the autumn/winter months while the lower panel shows those for the spring and summer months. Because Clark's sensible heat flux data only extend over the period 1951–57, and because no other heat flux data exist over the North Pacific, the statistical analysis was restricted to that time period.

The correlations between anomalous sensible heat flux and 700 mb height fields during the autumn and winter seasons in the upper panel of Fig. 8 are nearly always negative, with a distribution skewed toward values ranging from −0.3 to −0.5. These values represent significant pattern correlations as can be seen with Fig. 7. The months containing blocking ridge activity were designated by asterisks; in most cases (6 out of 8) the pattern correlations exceed −0.3.

The correlations between anomalous sensible heat flux and 700 mb height fields in the lower panel of Fig. 8 remain primarily negative, but with values that are mostly less than −0.3. Because it is difficult to assign degrees of freedom to this statistic, the determination of the significance of these correlation values is uncertain. Certainly, the degree of correlation is much less during the spring and summer months than it is during the autumn and winter months. Moreover, those months that had blocking ridge activity (denoted by asterisks) all had larger negative correlation coefficients.

An explanation of the persistent inverse relationships between anomalies of Q_s and 700 mb height can be found by examining the bulk formula for the calculation of sensible heat transfer:

$$Q_s=\rho C_p C_D W(T_s-T_a), \tag{1}$$

where ρ is the air density, C_p the specific heat of air, C_D the drag coefficient, W the wind speed, T_s the sea surface temperature, and T_a the air temperature near 1000 mb. From Clark (1967) and Kraus and Morrison (1966), fluctuations in anomalous sensible heat transfer on a time scale of months to a year is dominated by the fluctuating (i.e., anomalous) atmospheric parameters, W' and T_a'. If individual parameters in (1) are written in terms of mean and anomaly quantities, and we only consider the effect of fluctuations in T_a, then the anomalous sensible heat formula can be written

$$Q_s'=-\rho C_p C_D \bar{W} T_a'. \tag{2}$$

From the hydrostatic relation, the thickness between 1000 and 700 mb is a function of the mean virtual temperature (T_v) of the layer. In anomaly terms, the hydrostatic relation is written

$$(\Delta Z)'=\frac{R}{g}\ln\left(\frac{P_1}{P_2}\right)T_v', \tag{3}$$

where R is the gas constant, g the acceleration due to gravity, P_1 the pressure of the lower surface, and P_2 the pressure of the upper surface. Therefore, if we consider the surface air temperature to be proportional to the mean virtual temperature in the lower troposphere, then (2) and (3) can be combined, in which case

$$Q_s'=-a(\Delta Z)'=-a(H_{700}'-H_{1000}'), \tag{4}$$

where a is a constant of proportionality and H_p the height of the pressure surface p. Therefore, Q_s' is inversely proportional to the anomalous height of the 700 mb pressure (H_{700}').

These results indicate that during the autumn and winter seasons anomalous sensible heating is associated with anomalous heights of the 700 mb pressure surface and is induced by the anomalous virtual temperature associated with the latter. During the spring and summer months, this relationship breaks down somewhat although certain months display high correlations. These results suggest further that any mechanism that is offered to explain the formation of the blocking ridge

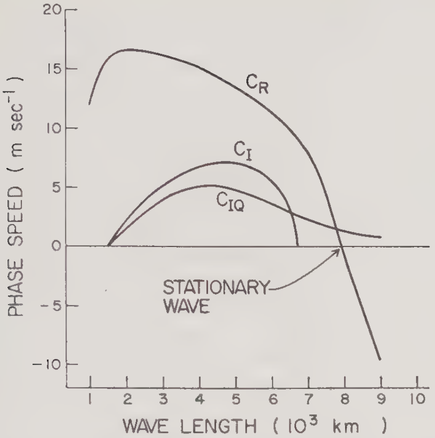

Fig. 9. The real (C_R) and complex (C_I) phase speeds of the baroclinically unstable waves, both with sensible heat transfer and without [taken from Haltiner (1965) for a mean wind of 30 m s^{-1} and a thermal wind of 10 m s^{-1}].

must take into consideration the flux of sensible heat between ocean and atmosphere.

6. The baroclinically unstable blocking ridge

The simplest hypothesis that can fit these descriptive results is that the mid-ocean blocking ridge is a baroclinically unstable long wave which derives its energy from the mean available potential energy in the atmosphere and is modified by sensible heat transfer from the ocean.

Normal baroclinically unstable waves have maximum growth rates on the order of a few days and propagate in the direction of the mean wind with a speed that is on the same order as that of the vertically averaged wind. Haltiner (1967) has investigated this instability mechanism in the presence of sensible heat exchange utilizing a two-layer, quasi-linear model of the atmosphere and treating the ocean as an infinite heat source. In his model, the perturbations in sensible heat flux are induced by air temperature fluctuations in a formulation similar to that found in the observed data discussed in the previous section. Furthermore, the magnitude of sensible heat transfer was set at a value ($Q=63$ cal cm^{-2} day^{-1}) that is about two-thirds of the average across the North Pacific during January (Clark, 1967).

Haltiner finds that the presence of sensible heat flux has an effect upon the dispersion relationship of unstable waves, shifting the maximum growth rate to shorter wavelengths, yet also allowing longer waves to become baroclinically unstable (Fig. 9). Furthermore, with sensible heat exchange, it becomes possible for baroclinically unstable long waves (~7000–8000 km) to become stationary and for slightly longer waves to be retrogressive. These results begin to describe some of the time and length scales of blocking ridge activity.

To be more quantitative (yet still realizing the limitations of this model), Haltiner also made a parametric study of the dispersion relations for different values of the mean thermal wind. The growth rate for stationary long waves between 7000 and 8000 km is plotted versus the strength of the thermal wind in Fig. 10. The latter is defined as the difference in the wind between 400 and 800 mb. Although we have no data at upper levels to determine the thermal wind between 400 and 800 mb over the North Pacific, the long-term zonally averaged shear at 45N over the globe is about 12 m s^{-1} (Mintz, 1968). If we assume this to be true also for the North Pacific, then the time scale of growth is about one month, slightly larger than those observed during the development of mid-ocean blocking ridges (Section 3). Furthermore, the length scale of these stationary waves is ~8000 km, again slightly larger than that of the blocking ridge (Section 4).

This theory not only accounts for the similar time and length scales of mid-ocean blocking ridge development, but also for the observed retrogressive development of quasi-stationary waves with slightly longer wavelengths (see Section 3). On the other hand, it does not explain why blocking ridges exist for only one or two months. The inability to predict what happens to the blocking ridge after it is fully developed is due to the quasi-linearity of the model; it can only indicate what happens in the initial growth stages. For a better understanding of what happens after the mid-ocean blocking ridge has formed, a simple global general circulation model could be useful.

7. Discussion of seasonal variability

Based upon the interpretation of the mid-ocean blocking ridge as a manifestation of baroclinic instability, we should be able to explain the seasonal character of blocking ridge development: Why does the

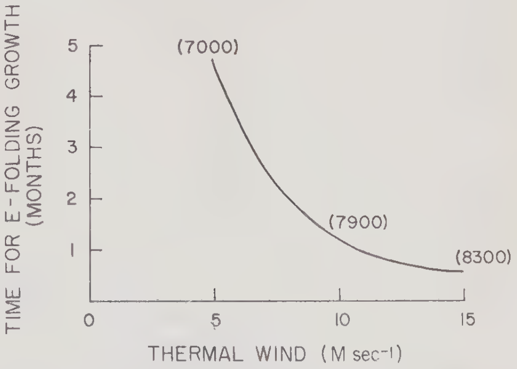

Fig. 10. A plot of the e-folding growth time of stationary, baroclinically unstable waves for different values of thermal wind (taken from Haltiner, 1967). The mean wind and sensible heat flux are held constant at 30 m s^{-1} and 63 cal cm^{-2} day^{-1}, respectively. Wavelengths are contained in parentheses.

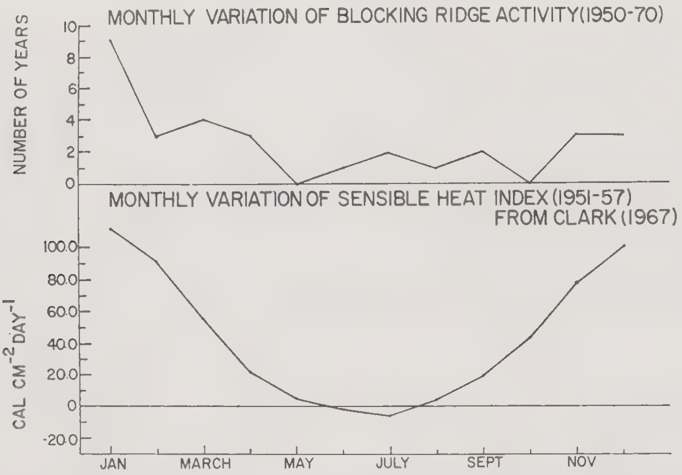

FIG. 11. Monthly variability of blocking ridge activity, equivalent to upper panel of Fig. 4, together with monthly variability of sensible heat flux index (defined in the text).

blocking activity form more often in the autumn and winter seasons and less often in spring and summer? From Fig. 7, the development of the stationary unstable wave owes its existence foremost to the presence of sensible heating from the ocean to the atmosphere. If this heating is reduced from Haltiner's values during the summer, then we might expect that blocking ridges would be absent during this time.

To see if this is true, consider the seasonal variability of blocking ridge activity from 1950–70, repeated from Fig. 4, displayed together with the seasonal variability of a sensible heat index (Fig. 11). This sensible heat index represents averages computed over the area from 135E to 135W at latitudes from 32.5 to 47.5N. The sensible heat data is taken from Clark (1967), extending from 1951–57. Note that the sensible heat index has a seasonal variability which resembles that of blocking ridge activity. More important, however, is the fact that on the average, sensible heating over the North Pacific is effectively zero from May through August during most of the spring and summer months. On the basis of Haltiner's theory, this would preclude the existence of blocking activity during this period of time, and, indeed, blocking activity is much suppressed during these months. On the other hand, during the autumn and winter months, the sensible heat index is between 50 and 100 cal cm^{-2} day^{-1}, values that are comparable to that (63 cal cm^{-2} day^{-1}) used by Haltiner. Therefore, it appears that Haltiner's theory can adequately explain the seasonal variability of blocking ridge activity.

These results also explain why pattern correlations between the anomalous sensible heat and 700 mb height fields in Fig. 8 are lower during the spring and summer months than they are in the autumn and winter. During spring and summer, very little sensible heat signal exists, and the noise contained in these computations becomes large enough to reduce the correlation much below what it is in the autumn and winter seasons when the signal is relatively large.

8. Year-to-year variability in blocking ridge activity and in the mean mid-latitude westerlies

Table 1 shows that mid-ocean blocking ridge activity varies from year to year. The number of months in autumn and winter seasons when blocking ridges occurred is plotted in the upper panel of Fig. 12. Autocorrelating this time sequence yields a 5–6 year dominant time scale during 1950–70. This is the same dominant time scale found when autocorrelating the autumn/winter mean surface and thermal wind indices over the same time period. This suggests that the year-to-year variability of blocking ridge activity may be related to the strength of the mid-latitude westerlies.

To determine what the relationship is between blocking ridge activity and the strength of the mid-latitude westerlies, consider the time sequences of the autumn/winter mean indices of the surface and thermal winds in the lower troposphere (two lower panels of Fig. 12), which represent averages computed over the area 32.5–47.5N and 135E–135W. The surface wind was computed from monthly mean pressure data (published by the Long Range Prediction Group of the National Weather Service) using the geostrophic assumption. The thermal wind for the lower troposphere between 1000 and 700 mb was computed from monthly mean thickness charts (prepared by Jerome Namias at Scripps Institution of Oceanography) using the thermal wind relation.

Correlating surface wind and thermal wind indices with the frequency of blocking ridge activity yields in each case a negative correlation of −0.78 that is significant at the 95% confidence level. Therefore, blocking ridge activity was higher than normal when both the surface wind and the thermal wind in the lower troposphere were weaker than normal. To make sure that the autumn/winter mean surface wind and thermal wind indices were not weak because of blocking ridge development, the autumn/winter means were recomputed using only those months of each year that were free of any ridging activity (Table 1). Comparing these time sequences (not shown) with those in the lower two panels of Fig. 9 shows little difference in the year-to-year variability, although the long-term mean in each case is about 5% higher.

Although both the surface wind and the thermal wind in the lower troposphere are weaker in those years when mid-ocean blocking activity is higher, it is still possible that the thermal wind is stronger in the upper troposphere. At present, no monthly mean data are at hand to test this possibility. However, the strength of the thermal wind at upper levels can be inferred from the strength of convective activity in the central equatorial North Pacific, which is directly related to the local Hadley circulation. Bjerknes (1969) explains this in the following way: warmer equatorial surface water increases convective activity along the ITCZ that leads to the release of latent heat at upper levels and causes the local Hadley circulation to intensify. This, in turn, results in an increase in the mean poleward transport of heat. The thermal wind in the subtropical jet stream (at approximately 30N) increases at upper levels, which results in intensified baroclinic instability (i.e., synoptic storms) that transfers excess equatorial heat poleward across the mid-latitude zone. This enhanced baroclinic instability also leads to Reynolds stresses that intensify the mean zonal westerlies. On the other hand, when equatorial waters are colder than normal, baroclinic instability at mid-latitudes is reduced in intensity since there is less mean available potential energy to draw upon. Furthermore, the Reynolds stresses are weak, and the mean zonal westerlies are reduced.

This explanation for the teleconnection between convective activity at the equator and the intensity of zonal westerlies has been supported by Rowntree (1972) using a hemispheric general circulation model constructed at the NOAA Geophysical Fluid Dynamics Laboratory at Princeton. Rowntree finds that when the central and eastern equatorial Pacific have higher than normal temperatures, the convective activity is greater, the local Hadley circulation is intensified, and the mid-latitude westerlies over the central and eastern latitude Pacific are intensified and displaced southward. Any sign of blocking ridge activity is absent. On the other hand, when the equatorial ocean has lower than normal temperatures, the Hadley Cell is weakened, with both blocking and non-blocking situations found in the mid-latitude westerlies.

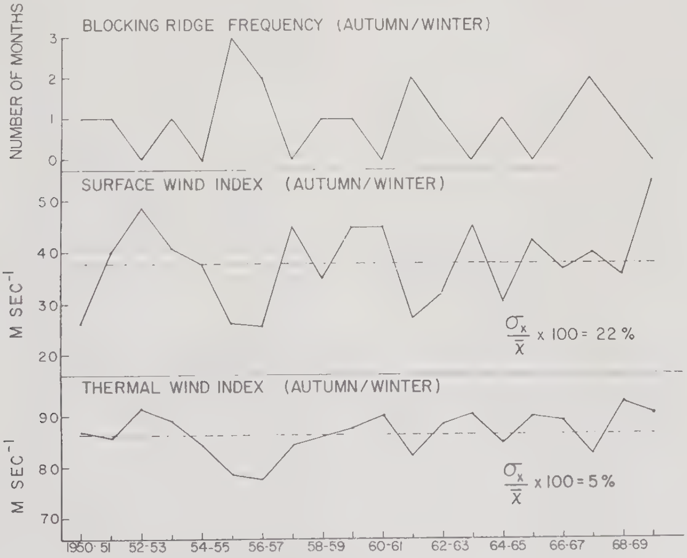

Fig 12. In the upper panel is the number of months of the autumn/winter season in each year when the blocking ridge activity was detected. In the lower panels are the time sequences of the autumn/winter mean surface wind and thermal wind indices. Both indices are taken from 32.5 and 47.5N and from 135E to 135W. The thermal wind is the difference in geostrophic wind between 1000 and 700 mb.

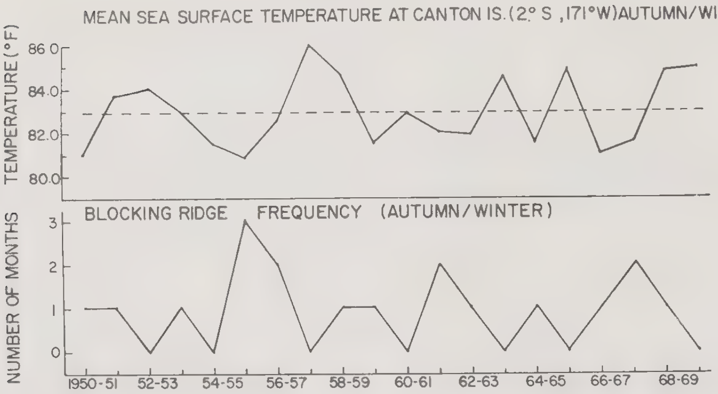

FIG. 13. Time sequence of the autumn/winter mean sea surface temperature at Canton Island (2S, 171W) and the time sequence of blocking ridge activity, repeated from Fig. 12.

These numerical results concerning blocking ridge development can be supported by considering in Fig. 13 the time sequence of autumn/winter mean sea surface temperatures near Canton Island (2S, 171W), and the autumn/winter frequency of blocking ridge activity. The sea surface temperature at Canton Island has been shown by T. Barnett (personal communication) to be representative of sea surface temperature over the entire central and eastern equatorial Pacific. Moreover, Bjerknes (1969) has shown that from 1955–67, the sea surface temperature at Canton Island (and indeed over the entire central and eastern equatorial Pacific) fluctuates in concert with the Southern Oscillation, as represented by sea level pressure anomaly at Djarkarta, Indonesia.

Autocorrelating the time sequence in the upper panel of Fig. 13 yields the same 5–6 year dominant time scale as found in the time sequence in the lower panel. Cross correlating these two time sequences yields a negative correlation (−0.69) that is significant at the 95% confidence level. The sign of this correlation is the same as that of the correlation between blocking activity and the thermal wind in the lower troposphere.

Therefore, it appears from both observation and numerical experiment, that a necessary, yet not sufficient, condition for blocking ridge activity to develop at mid-latitudes is that convective activity in the local Hadley cell over the central and eastern equatorial Pacific Ocean be lower than normal, which is associated with a reduction of the mean zonal westerlies in both the upper and lower troposphere of the mid-latitude westerlies. Moreover, it is clear that both the blocking ridge activity and the strength of the zonal westerlies at mid-latitude fluctuates from year to year in concert with the Southern Oscillation.

9. Discussion of year-to-year variability

If we consider year-to-year changes in the autumn/winter sensible heating, little change is found in the way sensible heating is correlated with 700 mb height (Fig. 8) and in its overall magnitude (i.e., the year-to-year variability is less than ±5% of the long-term mean). A similar statement can be made about year-to-year changes in the autumn/winter thermal wind index (Fig. 12). On the other hand, the year-to-year variability in the mean wind (assumed proportional to the surface wind) is about ±25% of the long-term mean. This gives us a clue for understanding the year-to-year variability in blocking ridge activity.

In Haltiner's theory, unstable wave growth depends upon the magnitude of the thermal wind and of the sensible heating from the ocean to the atmosphere. On the other hand, the wavelength of the stationary wave depends upon the magnitude of the mean zonal wind. In fact, the stationary wave has a wavelength L, determined by the Rossby wave dispersion relation:

$$L=2\pi(U_0/\beta), \tag{5}$$

where U_0 is the mean wind (vertically averaged) and β the meridional derivative of the Coriolis parameter.

In Haltiner's model, U_0 is set equal to 30 m s^{-1}, which from Mintz' global climatic data is only slightly higher than the mean westerly wind for winter. This value of mean wind yields through (5) a 7600 km wavelength, as can be seen in Fig. 9. Consider what would happen to this dispersion relation if the growth characteristics were to remain the same (i.e., C_{IQ} in Fig. 9 remains unchanged), but the mean winds were reduced by 25% (i.e., from 30 to 22.5 m s^{-1}) in agreement with observed year-to-year changes in the autumn/winter mean surface wind. The stationary wave would then be found at 6800 km, and, more important, the *e*-folding growth rate would be increased by a factor of 2 (see Fig. 14).

In this case, we would expect to see stationary blocking ridge development of length 6500–7000 km, with an *e*-folding growth time of about two weeks. These growth time scales are what has been observed by Rex (1951) in his study of blocking ridge development with synoptic data. The length scales are what we observe in the North Pacific in those years when the winds are weaker than normal.

In those years when the mean wind is stronger than normal by 25% (i.e., from 30 to 37.5 m s^{-1}), the stationary wavelength would be 8700 km, with an *e*-folding growth rate nearly half the normal rate. Therefore, not only would the allowable unstable stationary waves be longer than the zonal dimensions of the North Pacific basin, but the *e*-folding growth times would be about two months. Therefore, it seems that blocking ridge development is precluded in those years of intense westerly winds, which agrees with observation.

10. Conclusions

From this description of mid-ocean blocking ridge activity, a number of results can be summarized:

1) The blocking ridge over the central North Pacific is a finite-amplitude, quasi-stationary perturbation that is superimposed upon the otherwise quasi-zonal mid-latitude westerlies. It is usually centered near 170W, in the center of the North Pacific basin, and has a typical wavelength of 7000 km which also happens to be the width of the North Pacific at 40N. This suggests that mid-ocean blocking ridge activity owes its existence to the marine environment.

2) The time development of the mid-ocean blocking ridge has been previously determined by Rex (1951) to be from 1–2 weeks. From the monthly mean data presented here, the duration of the blocking activity is found to extend not more than 2–3 months in any one year.

3) A study of the seasonal variability of mid-ocean blocking ridge activity shows that blocking is more intense in the autumn and winter months (defined as October–March) and less intense in the spring and summer months (April–September).

4) Because blocking ridge activity is confined to the marine environment during autumn and winter seasons, the sensible heat transfer from the ocean to the atmosphere was thought to be important in its development. This is indeed the case; the anomalous distribution of sensible heat transfer during the autumn and winter seasons was strongly correlated (inversely) with the anomalous 700 mb height associated with blocking ridge development. Above-normal sensible heat exchange was found under the associated troughs and below-normal heat exchange under the ridge itself. This anomalous heat flux distribution arises in response to anomalous air temperature fluctuations associated with the blocking ridge development.

5) A study of year-to-year variability in autumn/winter blocking ridge activity shows that it is intense in those years when the surface wind and the thermal wind in the lower troposphere are both weaker than normal (correlated at −0.78).

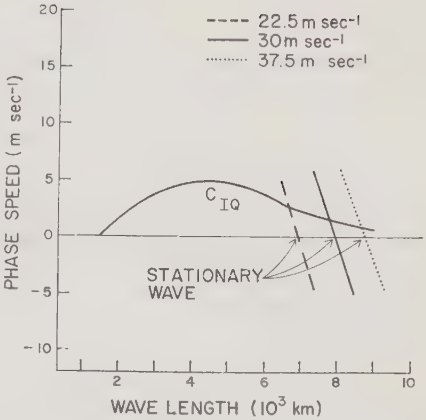

Fig. 14. Figure 9 repeated where C_R is plotted for three different values of mean wind (22.5, 30.0, 37.5 m s^{-1}) representing low, normal and high values, respectively.

6) The autumn/winter blocking ridge activity and the strength of the mean zonal westerlies fluctuate from year to year in concert with the Southern Oscillation.

Because the formation of mid-ocean blocking ridges occurs most often in autumn and winter months when the mid-latitude westerlies and sensible heat exchange are at their maximum values, the hypothesis is formed that blocking activity is due to baroclinic instability processes which are modified by sensible heat transfer between ocean and atmosphere. To support this hypothesis, appeal is made to the theoretical results of Haltiner (1967) who has established that for normal winter values of mean wind, thermal wind and sensible heat exchange, a stationary wave of 8000 km length scale has an *e*-folding growth time of about one month. These scales are somewhat larger, but similar to those observed for blocking ridge development over the North Pacific.

The seasonal variability of blocking ridge activity emphasizes the importance of sensible heat exchange between ocean and atmosphere to the baroclinic instability of stationary waves. In the absence of sensible heat exchange, stationary waves cannot be made unstable since their wavelengths are too long. However, with sensible heat exchange the long waves are made unstable, and stationary waves can grow. We observe them as mid-ocean blocking ridges. The reason blocking ridge activity is much reduced in spring and summer over that in autumn and winter is because from May to September the net sensible heat exchange over the mid-latitude North Pacific (Fig. 6) is almost negligible.

The year-to-year variability of blocking ridge activity emphasizes how well Haltiner's model agrees with observations. Earlier in this section, we stated that for normal winter values of mean wind, thermal wind, and sensible heat exchange, the resulting length and time scales derived from Haltiner's model were slightly too large compared with observations. Yet, observation also shows that autumn/winter blocking ridge activity is most intense in those years when the mid-latitude westerlies are weaker than normal and that it is often precluded in those years when the mid-latitude westerlies are stronger than normal. It is established that the year-to-year variability in the thermal wind and sensible heat exchange is small (i.e., ±5% of the long-term mean) but that the surface wind experienced a ±25% range of variability. Therefore, in Haltiner's model, keeping the thermal wind and sensible heat exchange the same, but decreasing the winter mean wind by 25%, reduces the wavelengths of the stationary unstable wave to 6800 km and decreases the time for *e*-folding wave growth to about two weeks. These time and length scales are in excellent agreement with observations.

Moreover, for mean winds 25% greater than the winter normal, the stationary wavelength is 8700 km, much larger than the North Pacific basin (7000 km wide), and has an *e*-folding growth time of from about two months. These time and length scales seem to be too large for stationary waves to realistically develop.

Although this application of baroclinic instability theory seems reasonable, it requires additional confirmation before it can be accepted as the dominant mechanism responsible for the formation of blocking ridges over the central North Pacific. Additional theoretical approaches to the problem are needed—for example, to determine what influence continental constraints and latent heat release have upon instability mechanisms over the ocean.

Acknowledgments. We thank Dr. Jerome Namias for allowing easy access to his data sources. Thanks also are extended to Messrs. Robert Born, Tony Tubbs and Ted Walker who did much to prepare the data for analysis. Much appreciation is given to Ms. Doreene Brown for her diligent preparation of the manuscript.

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A COMPUTER PROGRAM FOR ANALYSIS OF POLYMODAL FREQUENCY DISTRIBUTIONS (ENORMSEP), FORTRAN IV

Program ENORMSEP (Extended Normal Separator Program) separates a polymodal frequency distribution into its component groups where aging studies have not been or cannot be performed. The program calculates preliminary estimates of the number of size groups and their points of overlap using probit analysis and polynomial regression techniques. These preliminary estimates are then entered into NORMSEP (Normal Separator Program) (Hasselblad 1966), used as a subroutine, in order to complete the analysis.

Output data are generated both as listings and punched cards. Listings include at the option of the user: 1) table of values of the standardized normal distribution; 2) table of values of probabilities, standardized normal variables, and probits; 3) polynomial regressions and analyses of variance of probits; 4) table of residuals for the final regression; 5) table of roots corresponding to all regressions after taking second derivative; 6) tables for analyses for the separation of modes; 7) plots of observed and predicted values for the final regression; and 8) plot of the original frequency distribution. Punched card output includes the number of observed frequency distributions with their intervals and probits and regression coefficients for the polynomials.

Input data require the observed size frequency together with values for identification and control purposes. No more than nine size groups may be separated because of limits on the efficiency of parameter estimate in the polynomial regression.

This computer program was developed on an IBM 360/65I computer[1] using release 20.7 MVT/HASP system at the Statistical and Computing Center at the University of Hawaii. This computer program is capable of processing multiple sets of data. For a "typical" problem, the program takes about 1 min of central processing unit time and a total machine unit time of 1.5 min to run a single problem "individually." The requirement for core storage is 168K, where K is 1,024 bytes and where a byte is an address collection consisting of eight binary bits or binary digits.

A description of the program, including program listing as well as input and output for two examples, is available from the authors upon request.

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[1] Reference to this particular computer system does not imply endorsement of the product by the National Marine Fisheries Service, NOAA, but is given to provide the reader with a base for determining the cost of performing jobs with the particular computer system at his disposal.

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THE AMERICAN SAMOA LONGLINE FISHERY, 1966-71

HOWARD O. YOSHIDA[1]

ABSTRACT

Aspects of the longline fishery based at American Samoa covering the period from 1966 to 1971 are described. The fishery is discussed primarily as it relates to the albacore, *Thunnus alalunga*, and to a small extent the yellowfin tuna, *T. albacares*. The landings of albacore fluctuated between 17,722 and 28,310 metric tons from 1966 to 1971. Although no downward trend was evident in the relation between total landings and total effort, the relation between CPUE (catch per unit of effort) and effort showed a definite downward trend. Generally, fishing effort was confined to the north of lat. 20°S in the first and fourth quarters. In the second and third quarters large amounts of effort were also expended south of lat. 20°S. The length-frequency distribution of albacore showed that albacore sizes were stratified by latitude. North of lat. 20°S the size of albacore was rather uniform, in that only a single mode was evident in the length-frequency distributions. South of lat. 20°S two or more modes were evident.

The Honolulu Laboratory of NMFS (National Marine Fisheries Service) has been involved in assessing and monitoring the fisheries resources and developing the high seas fishing industry of the territories and island possessions of the United States in the Pacific Ocean. Part of this work included an investigation of the longline fishery based in American Samoa, which resulted in a report describing the history of the fishery and the distribution, apparent abundance, and size composition of albacore, *Thunnus alalunga*, landed from 1954 to 1965 (Otsu and Sumida 1968). The present report describes the status of the American Samoa longline fishery from 1966 to 1971; it is timely because the fishery has changed considerably since 1965, particularly with regard to the apparent abundance of albacore. Data published by Otsu and Sumida will also be used, especially where they are useful in illustrating certain continuing trends.

The earlier report included a rationale for confining the study to the albacore, the principal species of tuna taken in the fishery. The data were reliable only with respect to albacore because the catches of the other species were often not sold in their entirety to the canneries and, therefore, were not included in the catch reports by the vessel operators. However, as will be discussed later, the vessel operators have expended a considerable amount of effort to catch yellowfin tuna, *T. albacares*, in recent years. It is believed that most of the yellowfin tuna are now included in the catch reports and this species has become an important factor in the American Samoa longline fishery, and can no longer be ignored.

The tuna canneries, operated by Star-Kist Samoa, Inc. and the Van Camp Sea Food Company, depend entirely upon deliveries made by foreign flag vessels and fishermen. One of the most notable changes in the fishery over the years has been in terms of vessel nationality. The fishery began in 1954 with seven Japanese vessels. Vessels from Korea entered the fishery in 1958, and from the Republic of China (Taiwan) in 1964. The Japanese continued to increase their participation until 1963, but thereafter began a gradual withdrawal. On the other hand, the vessels from Korea and Taiwan greatly increased in number until the fleet reached a peak in 1967. Due largely to the withdrawal of the Japanese, the fleet has decreased since 1967. During the last quarter of 1971 there were 209 vessels in the fleet, consisting of 4 from Japan, 90 from Korea, and 115 from Taiwan.

SOURCES OF DATA

The data in this report were obtained through the operation of a field station in American Samoa, established in 1963, and manned continuously through December 1970 by personnel from NMFS, Honolulu. In January 1971 the field station was taken over by the Office of Marine Resources, Government of American Samoa. In the begining, the length, weight, and sex of 50 albacore, randomly chosen, were obtained from each trip landing. For various reasons, e.g.,

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changes in cannery operating procedures, changes in the sampling procedures were necessitated in subsequent years. The collection of sex and weight data was discontinued in early 1971. Catch and effort data have been provided voluntarily by the fishing vessel operators from about 75% of the fishing trips.

The longliners on some occasions fish widely scattered areas on a single fishing voyage. Since there is no way to determine the origin of each fish in the catch and because the fish are sampled at random at the docks, it is probable that some samples included fish from several different locations. This problem was minimized by summarizing the length data by large geographical areas.

ANNUAL LANDINGS OF ALBACORE AND YELLOWFIN TUNA

Except for dips in 1961 and 1964, the albacore landings increased steadily from 1954 to 1965 (Otsu and Sumida 1968). In the 6 yr that followed, the landings fluctuated between 17,722 and 28,310 metric tons (Table 1).

The gain in importance of yellowfin tuna can be seen in the increased landings in the later years (Table 1). After a period (1954 to 1964) of reported landings of less than 2,500 metric tons, the reported landings increased substantially and fluctuated between 4,514 and 8,567 metric tons from 1965 to 1971.

APPARENT ABUNDANCE OF ALBACORE AND YELLOWFIN TUNA

Otsu and Sumida (1968) used various indices of apparent abundance in discussing the status of the fishery for albacore during 1954 to 1965. These indices included catch per trip, catch per day, and catch per 100 hooks. However, because data on number of hooks fished per day were not available for the entire period of their study, they elected to use the fishing trip as the basic measure of effort in analyzing the apparent abundance of albacore. They also examined the relation between catch and effort, and CPUE (catch per unit of effort) and effort, in evaluating the effect of fishing on the stock.

Ideally, in considering the mean annual CPUE as an index of apparent abundance, the fishery should affect all portions of the stock(s) under consideration equally throughout the years. However, since the geographical limits of the fishery have been expanding each year, the situation is almost certainly not ideal. In this section I will extend some of the analyses of Otsu and Sumida to determine if any changes have occurred in the apparent abundance of albacore from 1966 to 1971. Since there are now 9 yr of effort data in terms of the number of hooks fished, I will make greater use of the catch per 100 hooks to determine the apparent abundance of albacore. It is assumed that fishing efficiency is not influenced by the nationality of the vessels, for Skillman (1975) found no evidence to suggest that any gear modification or change in the nationality of the fleet has caused any change in the catchability coefficient of albacore in the Samoan fishery.

TABLE 1.—Total annual albacore and yellowfin tuna landings in American Samoa, 1954-71.

	Landings (metric tons)	
Year	Albacore	Yellowfin tuna
1954	338	597
1955	1,760	1,628
1956	3,680	2,113
1957	5,873	1,537
1958	9,869	2,458
1959	10,292	1,780
1960	10,852	1,134
1961	9,740	1,331
1962	13,326	1,406
1963	13,972	2,057
1964	10,652	2,452
1965	15,591	4,514
1966	25,278	6,531
1967	28,310	5,326
1968	17,722	7,337
1969	18,767	8,207
1970	23,875	7,689
1971	22,193	8,567

Apparent Abundance of Albacore

Otsu and Sumida (1968) analyzed the mean annual CPUE of albacore from 1954 to 1965 in terms of the catch per trip. They believed that the catch per trip was a satisfactory measure of apparent abundance because their analysis showed a close relationship between the monthly average catch per trip and the monthly average catch per day. However, there are some basic shortcomings in the catch per trip. One is that the catch per trip of any vessel is limited by its fish-holding capacity. Also, as indicated by Otsu and Sumida (1968), the catch per trip is influenced by changes in the number of days fished per trip and by changes in the size composition of the vessels in the fleet. Changes in the number of hooks fished per day can also affect the catch per trip. The data do indeed show that the mean number of days fished per trip has increased during recent years (Table 2). The increase in the mean number of days fished per trip may also, in part, indicate change in the size of the vessels. That is, larger vessels, which presumably have larger fish-holding capacities, probably fish more days to obtain a full load of fish.

TABLE 2.–Total trip length, days spent fishing, and traveling time per trip by longline vessels based at American Samoa.

Year	Mean number of days		
	Total trip length	Fishing time per trip	Traveling time per trip
1963	42.35	26.12	16.23
1964	41.26	27.39	13.87
1965	48.79	32.09	16.60
1966	50.58	33.74	17.05
1967	62.13	38.03	23.50
1968	68.02	43.20	24.82
1969	67.34	44.25	23.08
1970	70.74	45.03	25.72
1971	84.16	52.03	32.13

In their analysis of the apparent abundance of albacore from 1954 to 1965, Otsu and Sumida (1968) indicated that the mean catch per trip increased from 1954 through 1960 and then fell slightly and stabilized at a lower level in 1963-64. A continuation of this analysis (Figure 1) showed that the mean catch per trip continued to fluctuate around this lower level with no definite upward or downward trend. It is possible that the mean catch per trip is fluctuating near the mean fish-holding capacity of the vessels or near a level that is related to the profitability of the fishing trip. That is, a vessel may fish as many days as are needed to obtain a full load or until a catch that is at least profitable is obtained. The trip, as an index of effort, does not take this factor into consideration, and, therefore, the catch per trip is not an accurate indicator of the apparent abundance.

It would be useful then, to compare the catch per trip with the catch per day, which is not affected by as many variables as the catch per trip. The mean annual catch per trip from 1959 to 1971 fluctuated between 29.9 and 38.2 metric tons (Figure 2) and, as noted earlier, did not reveal any obvious trends. The mean annual catch per day during the same period fluctuated between 0.7 and 1.7 metric tons, and, contrary to the catch per trip, declined after 1962 suggesting that the longline vessels are fishing more days to compensate for the reduced catch per day. The mean total length of a fishing trip, number of days spent fishing, and number of days spent traveling on each trip (Table 2) all showed an increasing trend from 1963 to 1971, which indicates that, in general, the vessels are traveling farther away from the home base to fish and are fishing more days per trip.

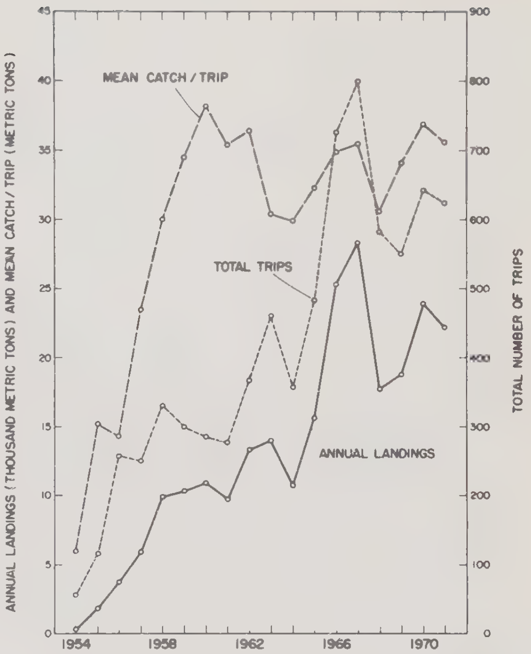


FIGURE 1.–Total number of fishing trips, mean catch of albacore per trip, and annual albacore landings, 1954-71.

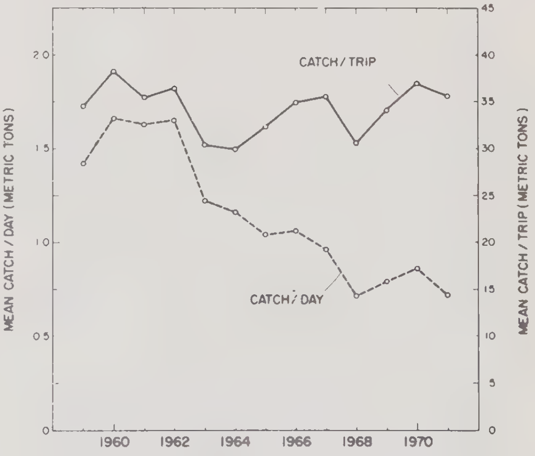


FIGURE 2.–Comparison of the mean catch per day and mean catch per trip of albacore, 1959-71.

The relation between the annual total landings of albacore and the total fishing effort (number of fishing trips) indicated that the annual landings increased with increasing fishing effort from 1954 to 1965. Based on this analysis, Otsu and Sumida (1968) concluded that the point of maximum yield of albacore had not been reached in the American Samoa-based fishery. The fishing effort continued to increase subsequent to 1965, and reached a peak of close to 800 fishing trips in 1967. The albacore landings also continued to increase with the increased effort. The relation between the annual landings and the effort, in total number of days fished, from 1959 to 1967 also showed that the landings increased with increasing fishing effort (Figure 3). The mean catch per day plotted against effort in total number of days fished, however, shows a decline in the CPUE from 1959 to 1971 with increasing effort (Figure 4).

As noted earlier, our laboratory has been obtaining, from the vessel operators, effort data in terms of number of hooks fished since 1963. Using these data, the mean monthly catch per 100 hooks of albacore from 1963 to 1971 was computed (Figure 5). A salient feature of Figure 5 is that the mean monthly CPUE fluctuated much more from 1966 to 1971 than they did from 1963 to 1965. It is not clear what caused this change in trends in the monthly CPUE after 1965. One possibility is that it is related to a geographical change in fishing effort. As will be discussed in more detail in another section, in the years after 1965 more fishing effort has been expended in latitudes south of lat. 20°S where good CPUE's of albacore are obtained in the second and third quarters of the year. This fact could also account for the definite peak in abundance of albacore in June or July during 1966 to 1971. It is also evident, however, that there is a slightly declining trend in the CPUE from 1963 to 1971.

A plot of the total annual catch of albacore against the estimated total annual effort in number of hooks fished from 1963 to 1971 is shown in Figure 6. During this period the estimated total effort ranged from about 13,165,000 to 51,092,000 hooks and the annual albacore catch from 10,652 to 28,310 metric tons. With some minor exceptions, there was a strong positive relation between the annual catch and effort for the 1963-71 period. Generally, the catches increased with increased fishing effort. Suda (1971) also found a similar relationship between albacore catch and fishing effort in the South Pacific from 1952 to 1968.

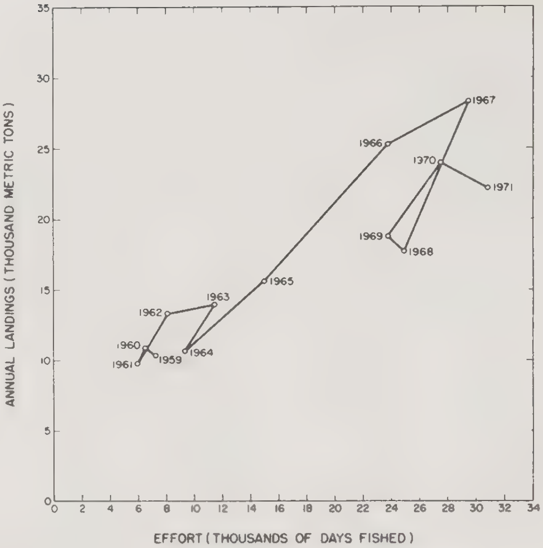


FIGURE 3.—Relation between annual landings of albacore and effort.

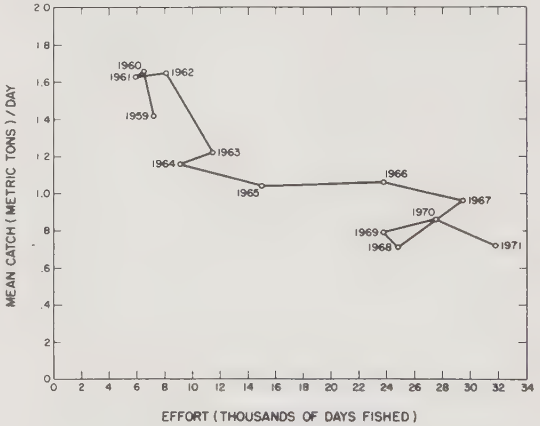


FIGURE 4.—Relation between mean catch of albacore per day and effort.

In Figure 7 is plotted the CPUE in number of fish and in weight per 100 hooks fished against the estimated total annual number of hooks fished from 1963 to 1971. Both plots show a negative relation between CPUE and effort; the CPUE decreased with increased fishing effort. Thus, although the catch has been increasing with increasing effort, it appears that the fishery has had some effect on the stock size in that the CPUE has been declining with increasing effort.

The analyses above reflect average conditions of

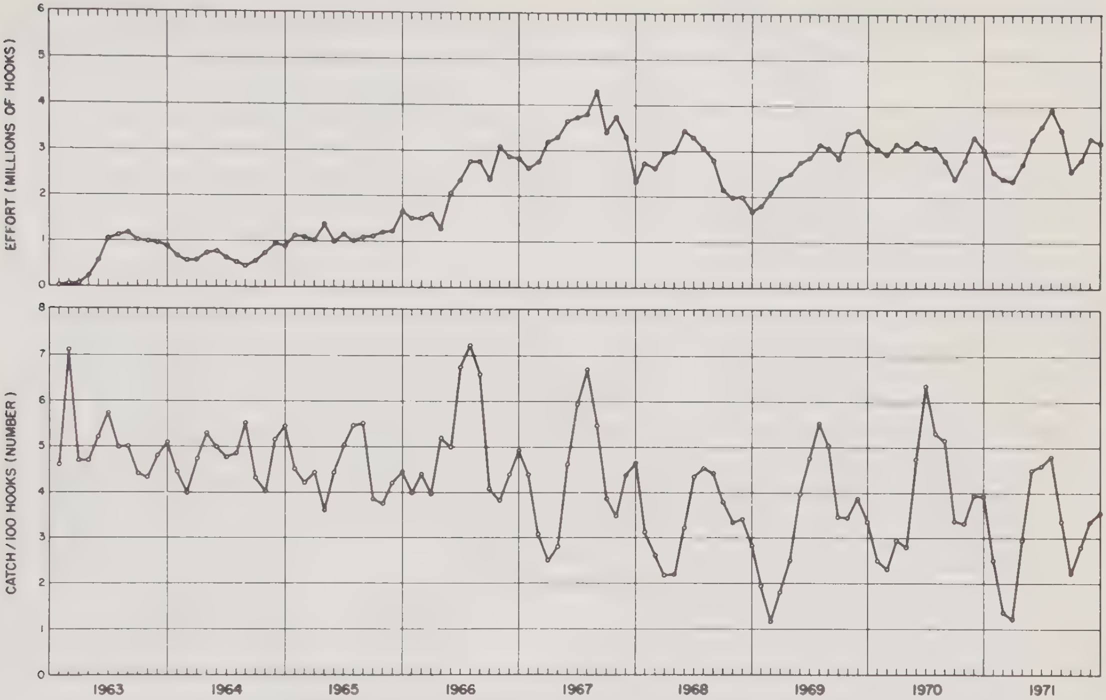


FIGURE 5.–Monthly mean albacore CPUE and effort, 1963-71.

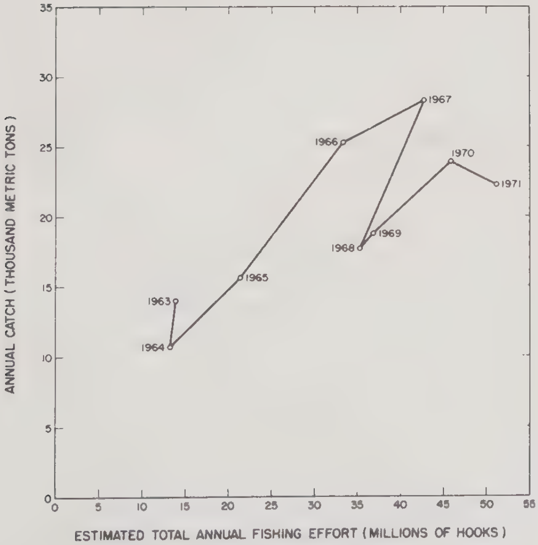


FIGURE 6.–Relation between total catch of albacore and total effort, 1963-71.

the fishery taken as a whole. It is of interest to compare the conditions north and south of lat. 20°S, especially since the geographic boundaries of the fishery have been expanding over the years. That is, it would be useful to see how the CPUE in the older fishing grounds north of lat. 20°S compares with that in the more recently exploited grounds south of lat. 20°S. The annual mean CPUE was computed for the area north of lat. 20°S, which represents the older fishing ground, and the area south of lat. 20°S, which represents the newer grounds (Figure 8). This analysis must be viewed with some caution, however, since total effort expended south of lat. 20°S is less than that expended in the north. Southern waters are fished heavily only in certain quarters of the year and these are the quarters when good catch rates are obtained. The mean catch rates in the southern waters therefore, may be overly weighted by the catch rates obtained in these quarters. However, the mean annual CPUE is higher in the newer grounds than in the old. The mean annual CPUE's

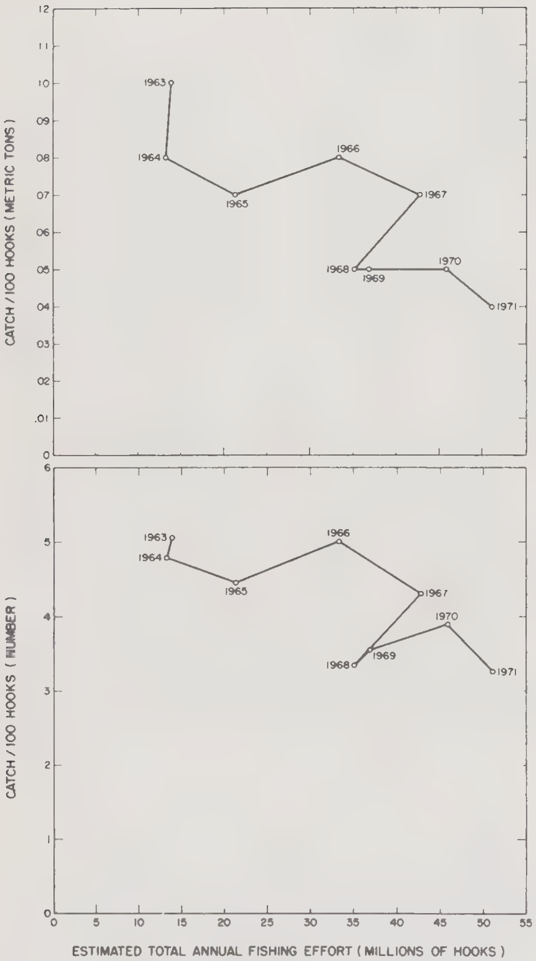


FIGURE 7.—Relation between CPUE of albacore in weight and numbers and total effort, 1963-71.

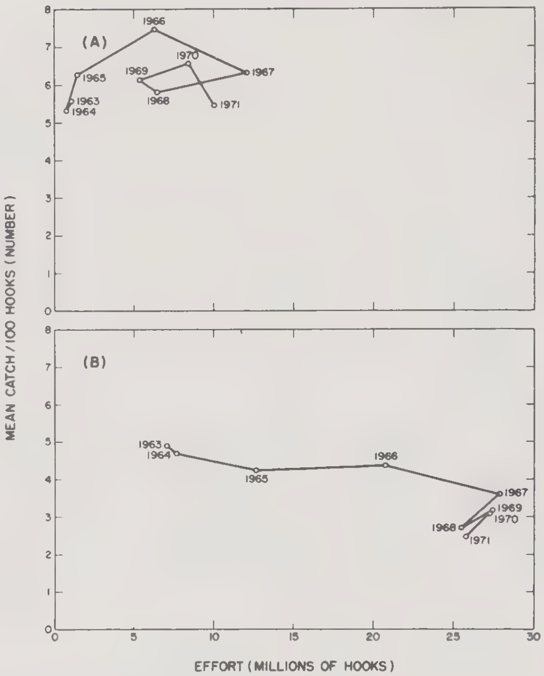


FIGURE 8.—Relation between CPUE of albacore and effort in areas south (A) of lat. 20°S and north (B) of lat. 20°S.

from 1963 to 1971 in the old grounds were all less than five albacore per 100 hooks, whereas in the new grounds they were all greater than five per 100 hooks during the same period. Another difference is that in the old grounds the mean CPUE has been declining with increasing effort. In the new grounds the CPUE increased with increasing effort from 1963 to 1966. In 1967, the CPUE declined slightly and from that year to 1971 the CPUE appears to have stabilized around six albacore per 100 hooks. These facts suggest that the albacore fishery has been able to maintain itself by continuously expanding geographically to take advantage of better CPUE in newer areas. It should be repeated here, however, that despite the expansion into new fishing grounds the overall trend for the fishery has been a decline in CPUE (Figure 5). Furthermore, in the southern grounds to which the fishery has expanded, the albacore catches, as will be shown in a later section, are composed of a large proportion of smaller fish. These smaller albacore may not be the optimum size at which to harvest the stock.

Apparent Abundance of Yellowfin Tuna

The discussion of the apparent abundance of yellowfin tuna will be primarily in terms of how it relates to the apparent abundance of albacore in the Samoan longline fishery. For one thing, although albacore are selectively fished for by the fleet, yellowfin tuna (and small numbers of other species) are also caught by the longlines, and the CPUE for one species may affect the CPUE of another (Rothschild 1967). The CPUE for one species may affect that for another species because, in computing the CPUE, the total effort expended was applied to the catch of each species without regard to the competition of the species for space on the gear. Furthermore, there is another complicating variable: the fishermen apparently seek out yellowfin tuna when the catches of albacore are poor. They do this by modifying the longlines to fish shallower and by fishing closer to the equator where yellowfin tuna catches are known to be better. The fact that the price of yellowfin tuna increased from an average of $270 a ton in 1965 to $394 a ton in 1970 may also have been a factor.

As noted earlier, the CPUE of albacore in relation to increased fishing effort has been declining, especially in the years subsequent to 1967. During 1968 to 1971, the yellowfin tuna CPUE was relatively good. It is apparent that as albacore fishing deteriorated, the vessels expended more effort to catch yellowfin tuna. The relation between albacore and yellowfin tuna CPUE in the Samoan longline fishery from 1963 to 1971 is shown in Figure 9. It appears that an inverse relation existed between albacore and yellowfin tuna CPUE: When yellowfin tuna CPUE was high, albacore CPUE was low, and vice versa. The correlation coefficient (*r* = -0.6636; df = 7), however, was not significant.

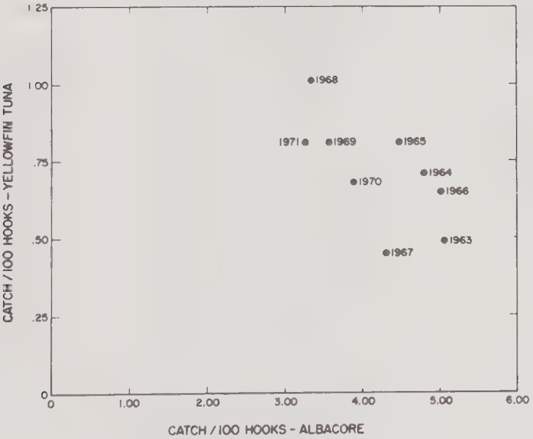


FIGURE 9.—Relation between albacore and yellowfin tuna CPUE.

SPATIAL AND TEMPORAL CONSIDERATIONS

Observations on the American Samoa fishery during the period from 1954 to 1965 indicated that the longline vessels shifted fishing grounds with season (Otsu and Sumida 1968). Seasonal and geographical differences in CPUE, however, were not readily apparent in the early years. In the following sections I will examine the spatial and temporal distribution of effort and CPUE in the fishery from 1966 through 1971.

Effort

In the early years of the fishery, the longliners confined their fishing largely to the vicinity of the Samoa Islands. Over the years, the vessels gradually extended their operations to more distant waters, and by 1965 the fishing grounds reached from about long. 175°E to about long. 120°W between the equator and lat. 30°S (Otsu and Sumida 1968). From 1966 to 1971 there was a further extension of the fishing grounds; the vessels fished from off the east coast of Australia to long. 100°W and from about lat. 10°N to about lat. 40°S. The fishing effort, however, was not uniformly distributed throughout the geographical limits of the fishery. Rather, there were distinct seasonal patterns in the spatial distribution of fishing effort.

A composite geographic distribution of the fishing effort on a quarterly basis for 1966 to 1971 summarized by 2° squares between the equator and lat. 40°S and east of long. 150°E is shown in Figure 10. As composite charts they can reflect only "average" conditions.

In the first and fourth quarters, the vessels generally fished to the north of lat. 20°S, and areas of concentrated fishing effort developed in about the same area each year. In the second and third quarters, the vessels expanded their operations to the south of lat. 20°S and, in addition to the usual area of concentrated effort to the north, an area of high fishing effort also developed to the south of lat. 20°S. However, there apparently has been a change from earlier years in the operations of the fleet because prior to 1966 the vessels fished in the north during both the first and second quarters (Otsu and Sumida 1968). These figures indicate that the vessels are moving south in the second quarter, earlier than previously. In any event, these seasonal changes in the concentration of fishing effort have been interpreted to reflect the movement of albacore in the South Pacific Ocean (Suzuki 1961; Otsu and Sumida 1968).

Catch Per Unit of Effort

The mean quarterly CPUE for 1966-71 plotted by 2° square areas is shown in Figure 11. In a

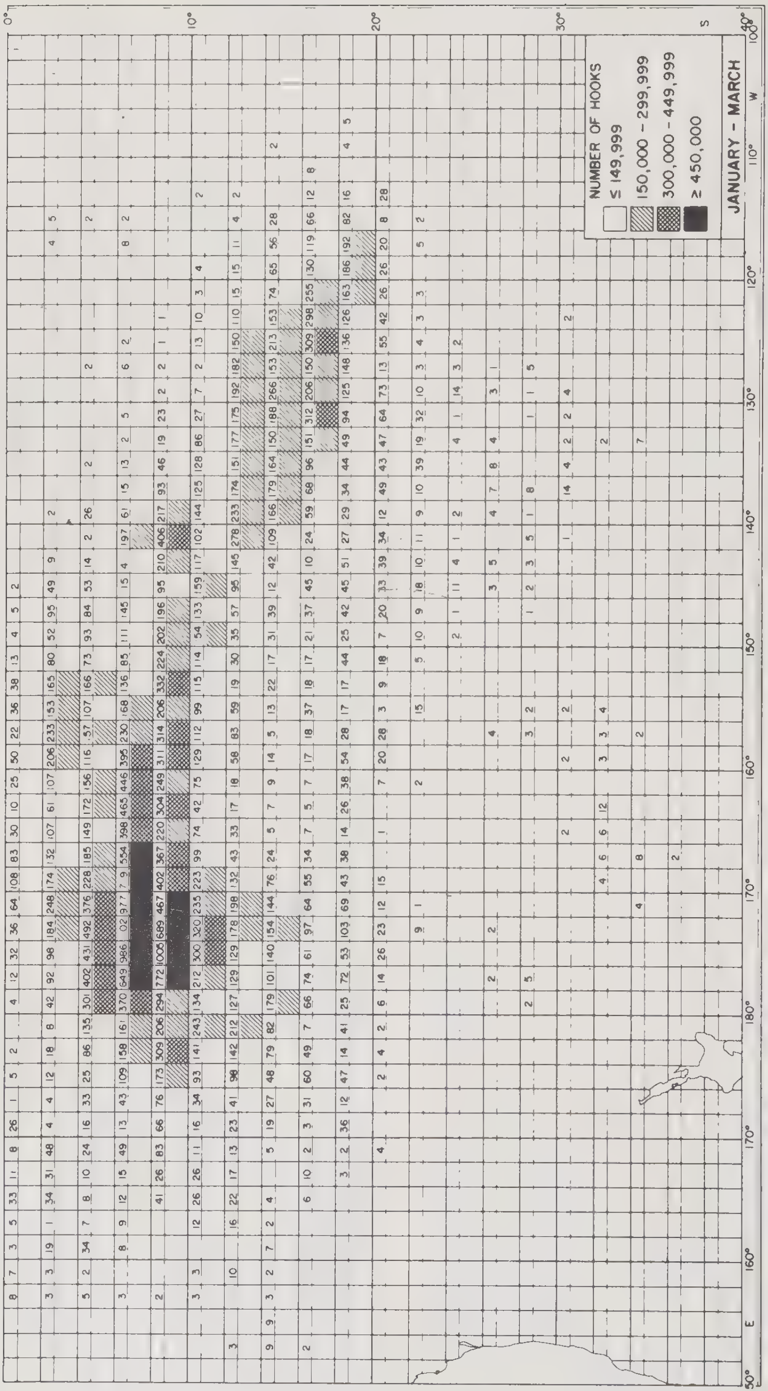
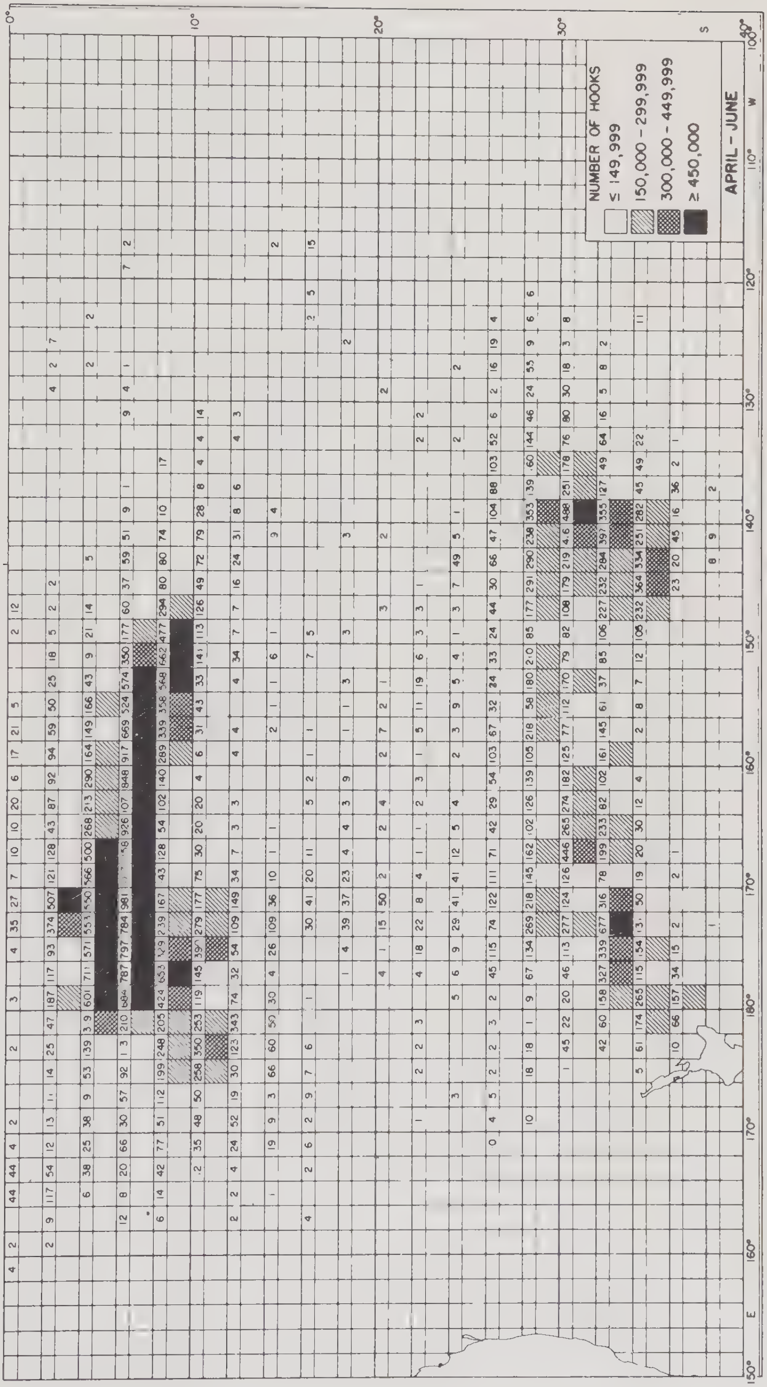

NUMBER OF HOOKS
≤ 149,999
150,000 - 299,999
300,000 - 449,999
≥ 450,000
JANUARY - MARCH
0°
10°
20°
30°
40°
S
150°
E
160°
170°
180°
170°
160°
150°
140°
130°
120°
110°
W
100°

FIGURE 10.—Quarterly geographic distribution of effort, 1966-71. The numbers in the figures are in thousands.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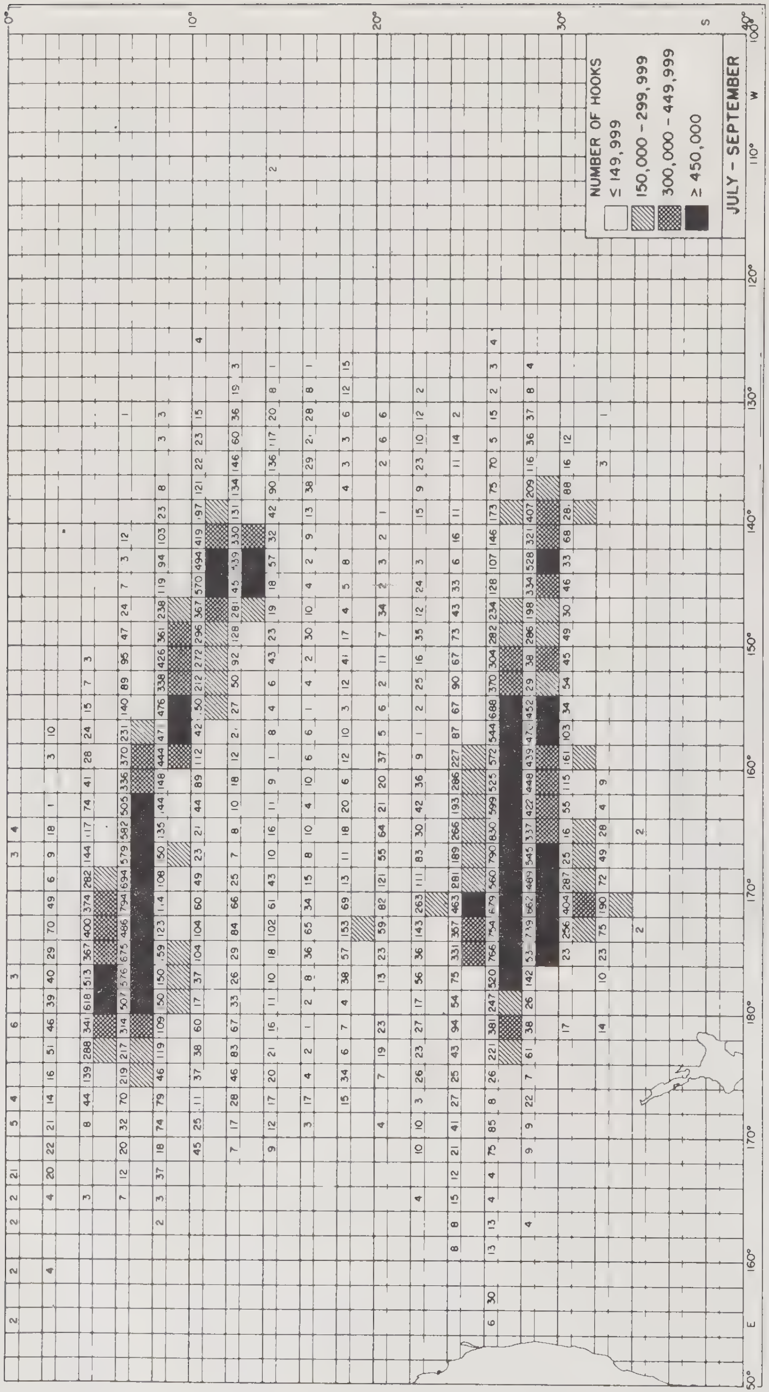
130°
120°
110°
100°
E
W
NUMBER OF HOOKS
≤ 149,999
150,000 - 299,999
300,000 - 449,999
≥ 450,000
APRIL - JUNE

FIGURE 10.–Quarterly geographic distribution of effort, 1966-71. The numbers in the figures are in thousands.–Continued.


NUMBER OF HOOKS
≤ 149,999
150,000 - 299,999
300,000 - 449,999
≥ 450,000
JULY - SEPTEMBER
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170°
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100°
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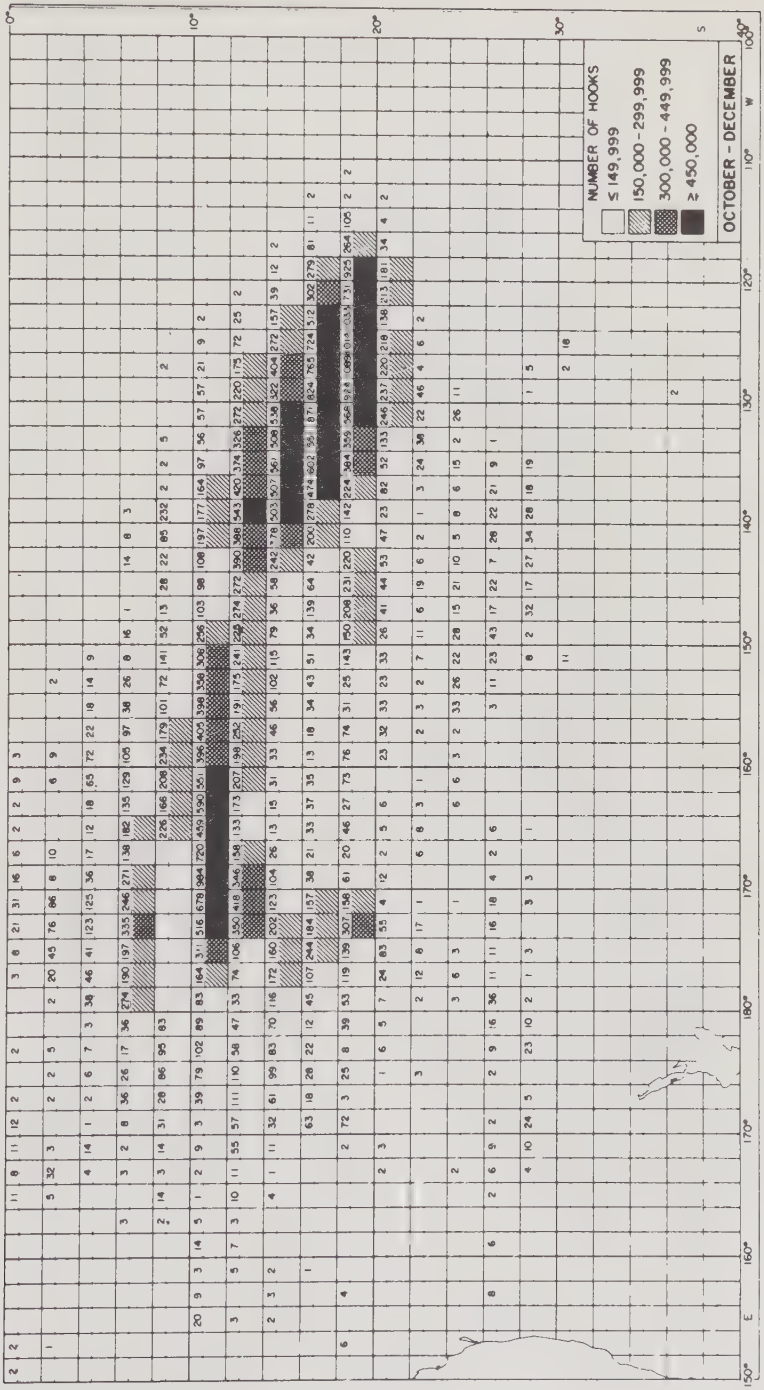
FIGURE 10.—Quarterly geographic distribution of effort, 1966-71. The numbers in the figures are in thousands.—Continued.


NUMBER OF HOOKS
≤ 149,999
150,000 - 299,999
300,000 - 449,999
≥ 450,000
OCTOBER - DECEMBER
0°
10°
20°
30°
40°
S
150°
E
160°
170°
180°
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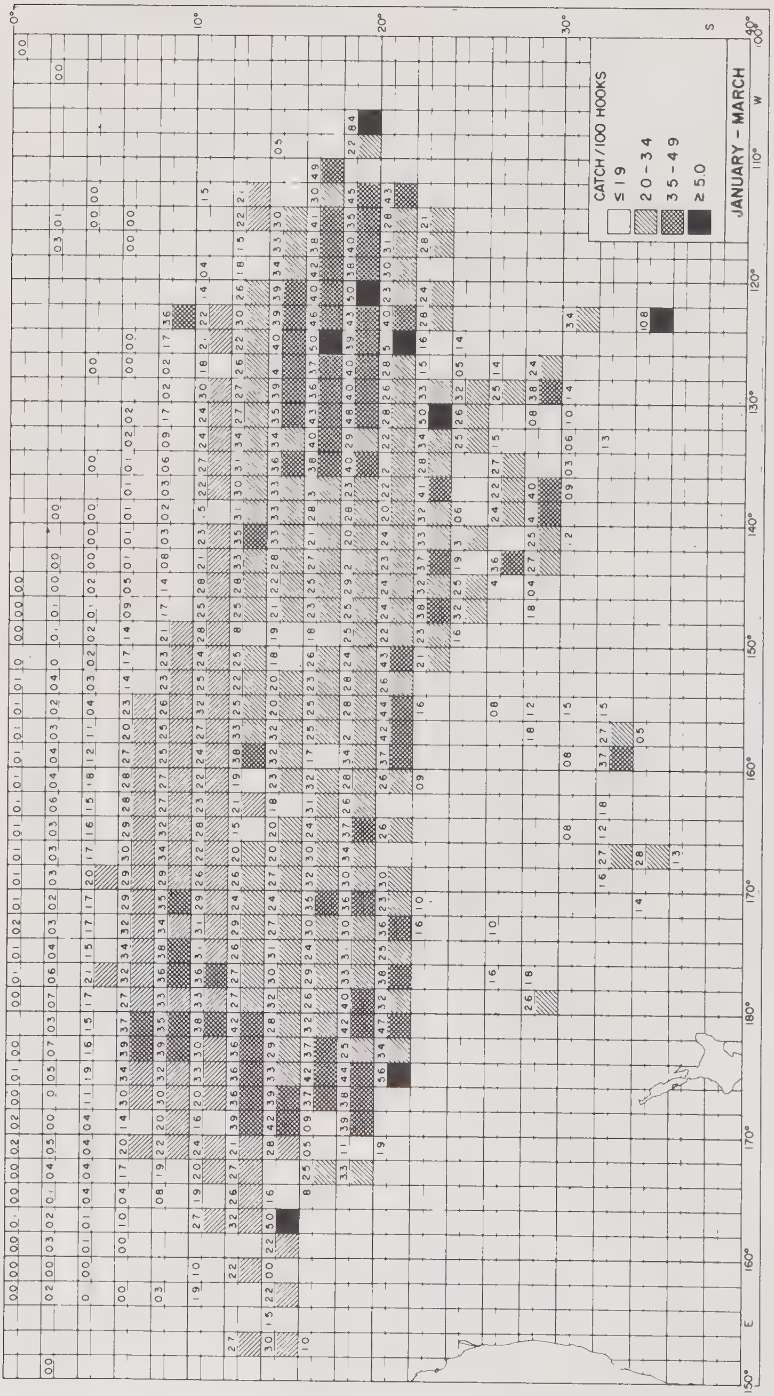
120°
110°
100°
W

FIGURE 10.—Quarterly geographic distribution of effort, 1966-71. The numbers in the figures are in thousands.—Continued.


CATCH / 100 HOOKS
≤1.9
2.0 – 3.4
3.5 – 4.9
≥5.0
JANUARY – MARCH
0°
10°
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S
100°
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FIGURE 11.—Seasonal and geographic distributions of albacore CPUE, 1966-71.

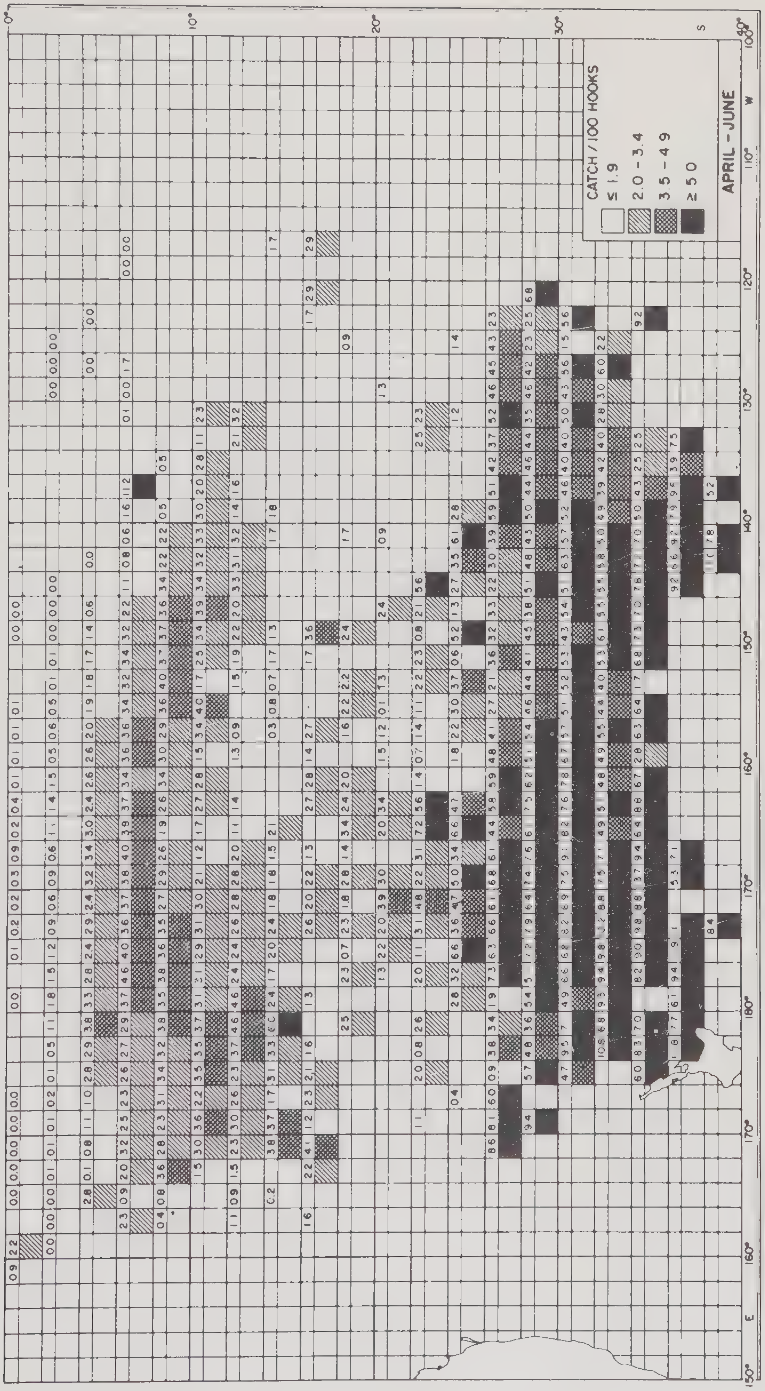
CATCH / 100 HOOKS
≤ 1.9
2.0 – 3.4
3.5 – 4.9
≥ 5.0
APRIL – JUNE
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FIGURE 11.—Seasonal and geographic distributions of albacore CPUE, 1966-71.—Continued.

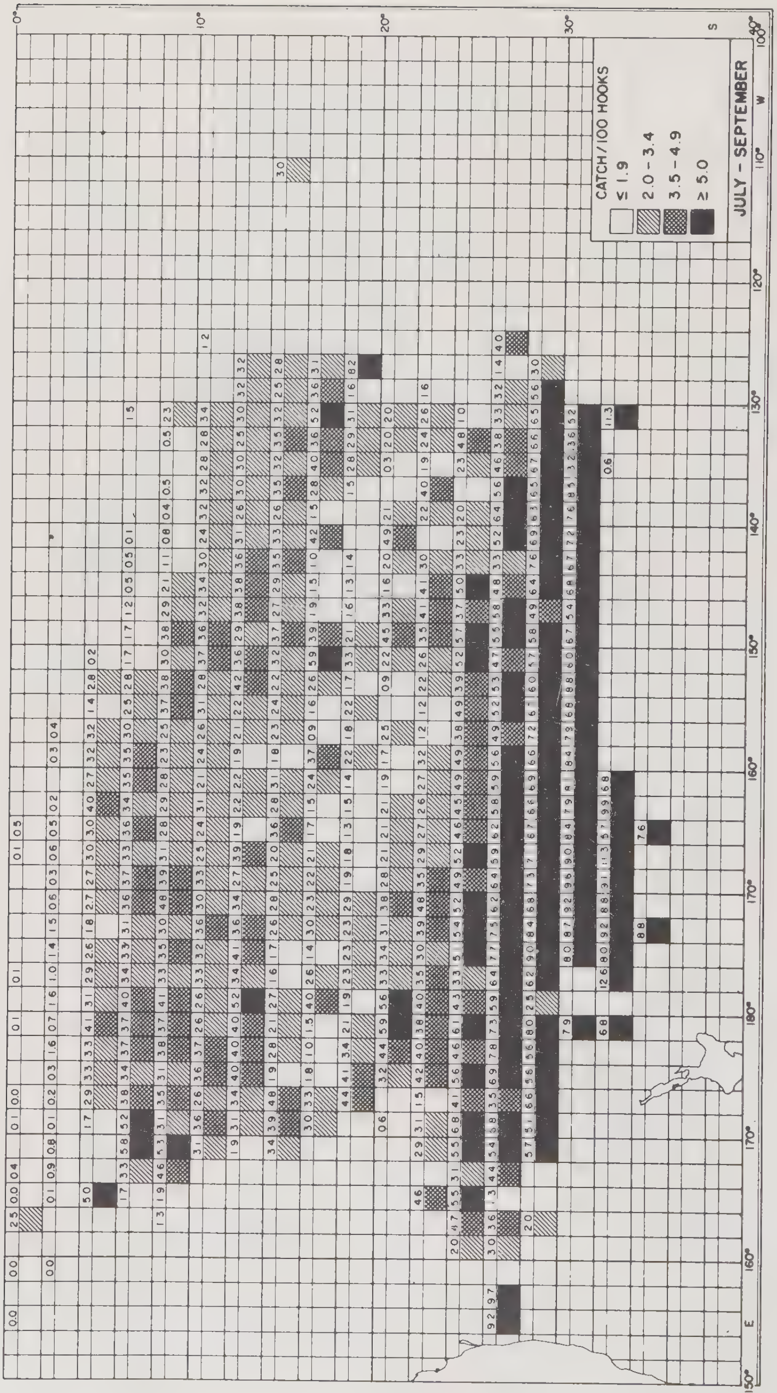
CATCH / 100 HOOKS
≤ 1.9
2.0 – 3.4
3.5 – 4.9
≥ 5.0
JULY – SEPTEMBER
0°
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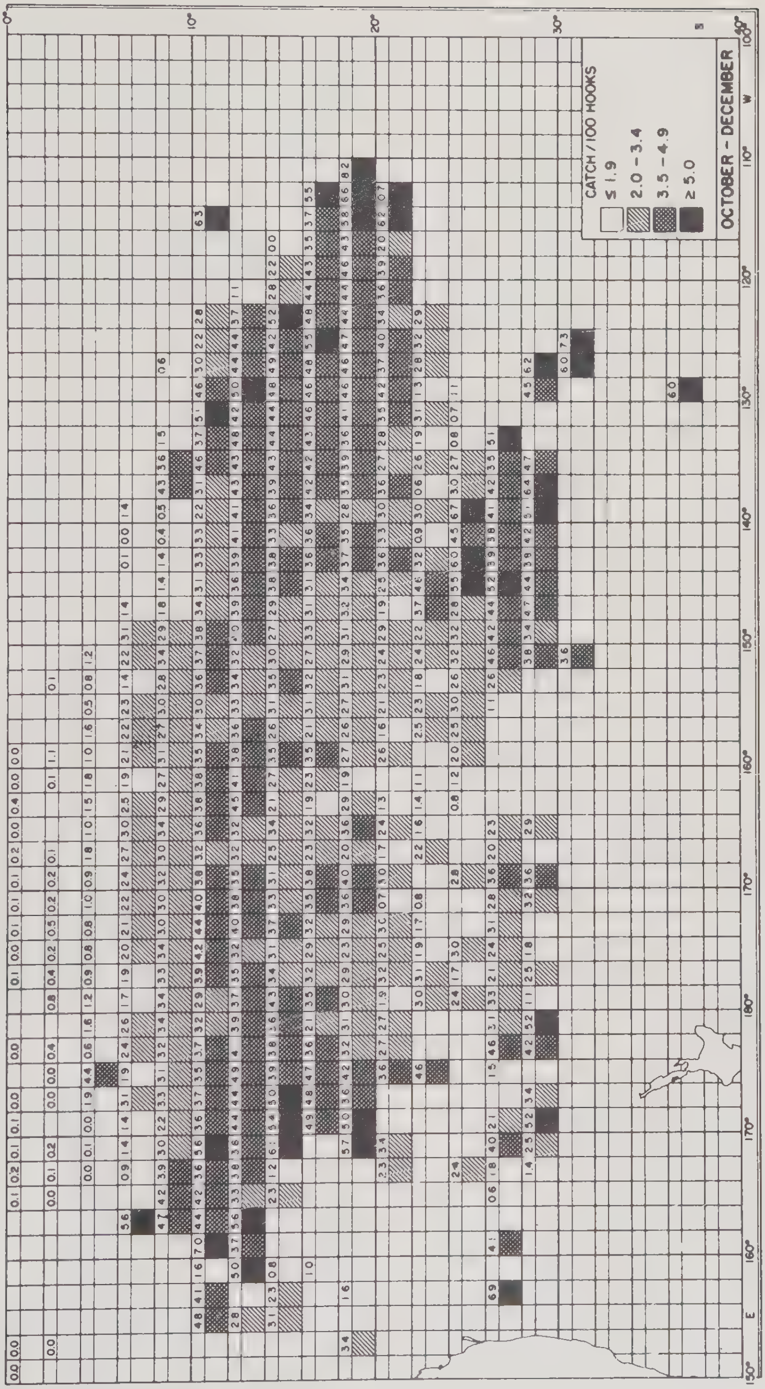
FIGURE 11.—Seasonal and geographic distributions of albacore CPUE, 1966-71.—Continued.


CATCH / 100 HOOKS
≤ 1.9
2.0 – 3.4
3.5 – 4.9
≥ 5.0
OCTOBER – DECEMBER
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30°
S
150°
160°
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FIGURE 11.—Seasonal and geographic distributions of albacore CPUE, 1966-71.—Continued.

similar analysis covering a period from 1963 to 1965, seasonal and geographical differences in CPUE were not readily apparent (Otsu and Sumida 1968). For some reason that is not immediately clear, a distinct seasonal pattern in geographical differences in CPUE has developed in recent years. In the first quarter, there appeared to be no pattern in the distribution of areas with high CPUE (greater than five albacore per 100 hooks). However, the CPUE was better in the east-west extremes of the fishery. In the second and third quarters, an area of high CPUE developed between lat. 25° and 40°S. The fishery was also well developed north of lat. 20°S in the second and third quarters but as in the first quarter there were no well-defined areas of high CPUE. The situation in the fourth quarter reverted to approximately what it was in the first quarter. However, in some years there was a tendency for an area of high CPUE to develop in the eastern extreme of the area fished between lat. 10° and 20°S.

Because of geographical and temporal variations in the distribution of the fishing effort, the description of the geographical and temporal changes in CPUE as given above is incomplete. As noted earlier, very little fishing effort was expended south of lat. 20°S in the first and fourth quarters. It would be of interest to determine whether a high CPUE could be obtained south of lat. 20°S also in the first and fourth quarters. The possibility exists, of course, that very little effort was expended south lat. 20°S in the first and fourth quarters because the fishermen know from past experience that poor catch rates are obtained during those periods. Honma and Kamimura (1957) suggested that albacore in the South Pacific make north-south migrations and that the fishing vessels follow the movements of the albacore. In the eastern Pacific tuna fishery, Griffiths (1960) showed that the bait boat fishermen were able, on the average, to concentrate their effort on high densities of yellowfin tuna about 70% better than if their effort had been random. The data indicate that the fishermen may be able to predict the movements of the albacore with some degree of success in that areas of high fishing effort were usually associated with areas of high CPUE. There were quarters, however, in which areas of high fishing effort did not coincide with areas of high CPUE. Then, too, the fishermen may avoid fishing south of lat. 20°S in the first and fourth quarters because of bad weather or unfavorable conditions.

One other interesting observation is the division of the fishery at lat. 20°S. As noted above, the fishery develops north or south of lat. 20°S but seldom straddles it. This appears to be a well-established phenomenon, for Koto (1966) has made the same observation. Koto mentioned belts of high catch rates in the area between lat. 10° and 20°S and between lat. 20° and 30°S, and a belt of low catch rates centered at lat. 20°S. The data also indicate that the latitudinal belt centered at lat. 20°S is also a low-effort area. The causes of this phenomenon are not clear.

SIZE OF ALBACORE

Because the canneries have changed the method of handling the fish, the albacore that are sampled for length are no longer being sexed. Consequently, in the analysis of the length distribution of albacore only the data collected from 1966 to 1970, when sex data were available, are presented.

A composite length-frequency distribution of male and female albacore taken by the fishery from 1966 to 1969 is shown in Figure 12. The fish

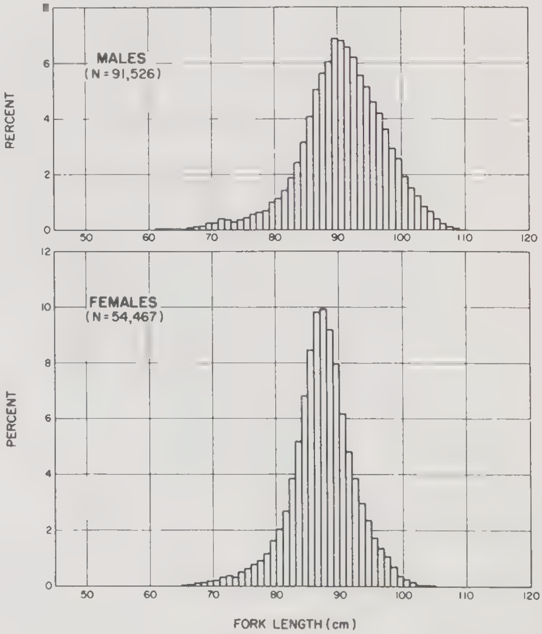

FIGURE 12.—Composite length-frequency distributions of albacore, 1966-69.

ranged in length from 50 to 120 cm. A single prominent mode was present in both the male and female distributions. For the males the mode was located at 91 cm and for the females at 88 cm.

The albacore size data were also summarized into smaller units of time and area to detect any variations which might exist. Initially the geographical area of the fishery was divided longitudinally at long. 150°W and by 10° of latitude from the equator to lat. 40°S. This was done on a quarterly basis, keeping all the years separate. This analysis did not indicate any obvious differences in the length-frequency distributions of albacore east and west of long. 150°W, nor did it show any consistent annual and seasonal differences within each geographical unit. There were, however, differences in the length-frequency distributions between the latitudinal subdivisions of the fishery. Therefore, the length data were rearranged by 10° of latitude but without regard to longitude, seasons, and year (Figure 13).

Almost without exception, the modal sizes of male albacore were larger than those of female

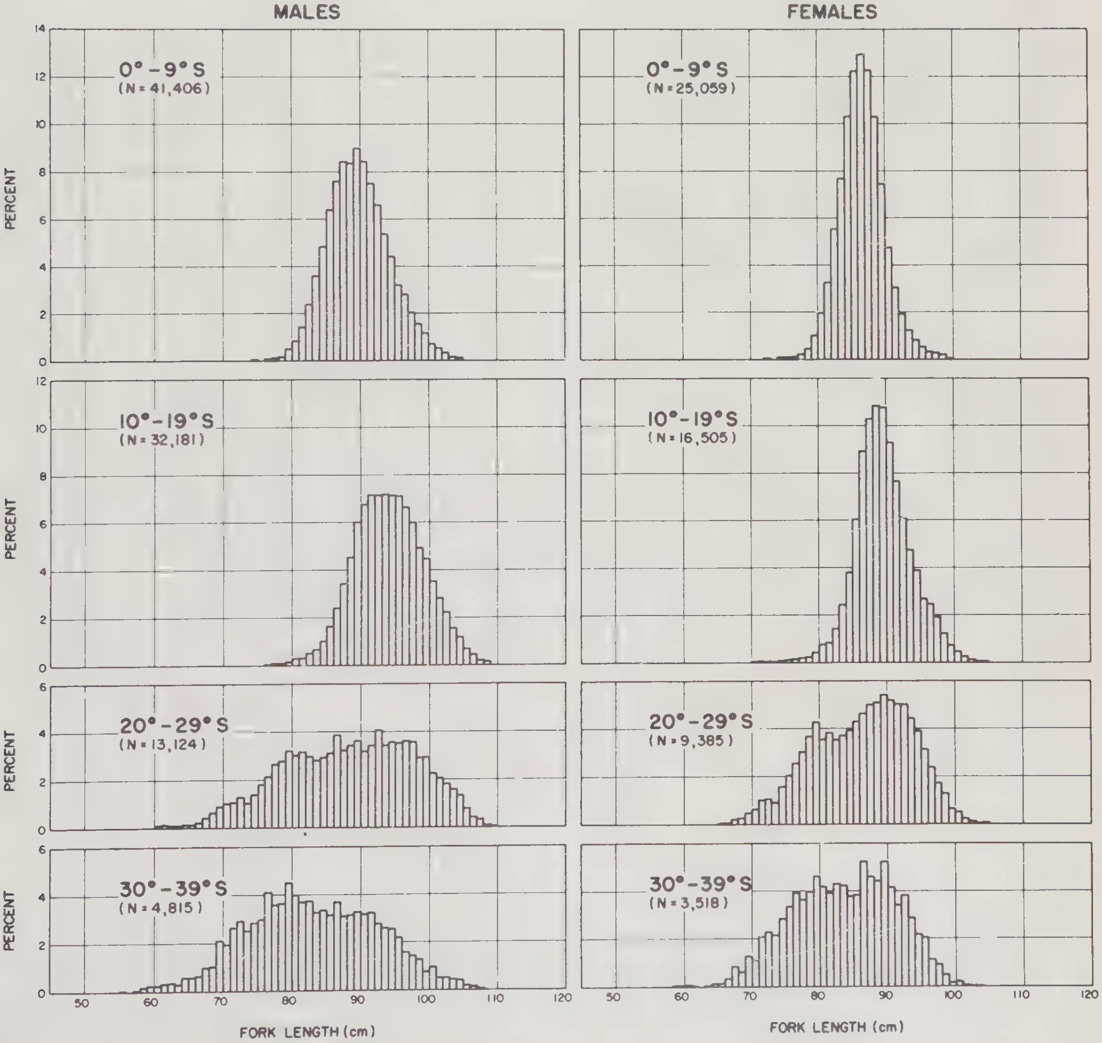

FIGURE 13.–Length-frequency distributions of albacore arranged by sex and 10° bands of latitude, 1966-70.

albacore in each of the latitudinal subdivisions. In the areas north of lat. 20°S, both male and female length-frequency distributions had a single well-defined mode. In the areas south of lat. 20°S the modes were less well defined. Koto and Hisada (1967) found a similar pattern in the length-frequency distribution of albacore in the South Pacific in 1961.

Otsu and Sumida (1968) computed the mean length of albacore in the fishery during the period from 1962 to 1965. They divided the fishery into 5° bands of latitude and noted that the fish were smallest near the equator, largest at lat. 20° to 25°S and tended to be smaller again south of lat. 25°S. The results agree in general with those of Otsu and Sumida; however, as seen above, the length-frequency distributions indicate a more complex situation than do the mean sizes. North of lat. 20°S the mean sizes may be good indicators of the general size of albacore because the length-frequency distributions showed that the fish were composed of single uniform size groups. South of lat. 20°S, the catches were composed of several size groups of fish and the mean does not indicate the presence of different size groups of fish. For example, although Otsu and Sumida stated that albacore south of lat. 25°S tended to be smaller, my data show that large fish were also present in these latitudes.

Although it is not readily apparent in the length-frequency distributions, there appears to be a declining trend in the mean size of albacore in the fishery. Otsu and Sumida (1968) noted that albacore taken in 1964 and 1965 were shorter on the average than those caught in 1963. My data show that the declining trend in the mean length of albacore has continued (Table 3).

TABLE 3.–Mean lengths of albacore, sexes combined, 1963-71.

Year	Mean length (cm)	Year	Mean length (cm)
1963	95.0	1968	89.8
1964	91.6	1969	90.4
1965	91.3	1970	88.6
1966	91.7	1971	91.5
1967	90.8		

The mechanisms that produced such a pattern in the distribution of sizes in the fishery are probably complex. The unique character of the length-frequency distributions among the four latitudinal bands must have resulted from some nonrandom distributional process. The larger numbers of smaller albacore in the more southern waters suggest that albacore are initially recruited into the fishery in the area south of lat. 20°S. The high CPUE experienced in the second and third quarters south of lat. 20°S may be an indication of this. Also, it has been shown that juvenile albacore which originate from spawning that takes place north of lat. 20°S migrate south as they grow larger (Yoshida 1971).

SUMMARY

A comparison of various indices of apparent abundance of albacore indicated that catch per day and catch per 100 hooks were better indicators of apparent abundance than catch per trip. The mean catch per day and catch per 100 hooks of albacore have generally declined over the years, which suggests that the apparent abundance of albacore has declined in the American Samoa longline fishery. To compensate for the reduced CPUE, the longliners fished more days per trip and traveled farther from the home base seeking areas of good catch rates.

The fishery apparently has had an effect on the albacore stock. Although the annual landings have continued to increase with increased fishing effort, the CPUE has declined. That the apparent overall effect was not greater was due to the fact that the fishing grounds have expanded, especially into areas south of lat. 20°S where good catch rates were obtained. The mean annual CPUE plotted against fishing effort for selected, discrete areas north and south of lat. 20°S indicated that the fishery has not as yet had as great an effect in the south as it has to the north. There are at least two possible reasons for the better condition of the fishery to the south. First, the area south of lat. 20°S has not been exploited as long as the area to the north. Second, it was shown that the albacore are first recruited into the fishery in the latitudes south of lat. 20°S, which may account in part for the higher apparent abundance.

There was some indication that there were temporal changes in apparent abundance of albacore south of lat. 20°S. Because of poor weather conditions or because the fishermen have learned through experience that catch rates are better during certain seasons, or a combination of these and other reasons, fishing effort expended south of lat. 20°S fluctuates seasonally. Areas of concentrated fishing effort were evident in the second and third quarters in the area south of lat. 20°S. Very little effort was expended in these waters in the first and fourth quarters. Good CPUE's were experienced in these areas of high fishing effort in the second and third quarters. Although there were some indications that the apparent abundance of albacore was low in the southern waters in the first and fourth quarters, more data are needed to show this conclusively.

The apparent temporal changes in CPUE in the southern waters may be related to seasonal changes in recruitment of albacore into the fishery. The length-frequency distribution of albacore in waters south of lat. 20°S showed that several size groups of fish were represented in the catches, including groups of small fish not found north of lat. 20°S. The good CPUE in the second and third quarters may indicate periods of active recruitment. Generally, the albacore were stratified by size latitudinally; however, no such stratification was evident longitudinally. North of lat. 20°S the catches were composed of fish of a single size group. South of this latitude, as already indicated, the catches were composed of several size groups of fish.

ACKNOWLEDGMENTS

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